BRITISH RAILWAY TRACK

DESIGN, CONSTRUCTION AND MAINTENANCE

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WISHFORD

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DESIGN, CONSTRUCTION AND MAINTENANCE

COMPILED BY A COMMITTEE OF
THE PERMANENT WAY INSTITUTION

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FOREWORD.

Those members of the Permanent Way Institution concerned in its educational activities have, for many years past, felt the need of a Text Book on practical permanent way work which could be recommended with confidence to their fellow members. When examinations qualifying for the Institution's Diploma were initiated in 1935 it became apparent that such a book was an essential contribution towards the educational programme, and that without it, further progress would be severely handicapped.

The Council of the Institution thereupon requested their Education Committee to produce such a book. The task set them was by no means light and before much progress was made, the Committee sustained the loss by death in 1938 of Mr. Robert Gurd, whose wide experience, enthusiasm and energy played so large a part in the conception of the book and in the foundation work on which it has now been completed.

It was not until 1939 that the Committee was able to persuade Mr. R. A. Hamnett to undertake the onerous duty of co-ordinating the work done by members writing independently, and it is due primarily to his painstaking efforts that the work so long in hand now becomes available.

It is unnecessary to explain how the outbreak of war in the Autumn of 1939 retarded the completion of the book.

The Committee has endeavoured within the set limits of size and price, to cover the whole field of the subject. Every effort has been made to write as simply as possible, so that the book may be of help to men who have had few opportunities for the study of mathematics or geometry. The Text Book has been compiled by men with practical experience of Railway Trackwork, and it is hoped that those more concerned with the theory and design of track, may also find material of value between its covers.

The confidence that their efforts would be of help to their fellow members has made pleasant the work of the Committee, and now that their labours are at an end they trust that their readers will furnish suggestions for corrections, improvements and additions, in the hope that the time is not far distant when they may assist in the production of a revised and better edition.

The Institution is indebted to the Chief Engineers of the British Railways for permission to include much of the data, and also to the Editor of *The Railway Gazette* for the loan of a number of blocks and permission to reproduce certain illustrations.

D.R.B.

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CHAPTER I.

EARTHWORKS, FORMATION AND DRAINAGE.

EARTHWORKS.

When the railway is planned an effort is made to locate it in such a route that the amount of material excavated from the cuttings is sufficient to form the necessary embankments. If this can be done, the expense of disposing of surplus excavated material, or of obtaining material for embankments from other sources, is avoided, although in some cases it is found that the excavated material is not suitable for forming embankments.

If the material from the excavation is not sufficient to form the necessary embankments the required material is generally obtained from borrow pits located close to the railway. In low lying country liable to flooding, the rail level is generally raised well above the highest known flood level of the site by forming an embankment, with material which may be obtained by excavating borrow pits parallel to, and on either side of, the railway.

The sides of cuttings and embankments are generally formed to a slope; the slope, or batter, chosen being slightly flatter than the "angle of repose" of the material, which is the steepest angle with the horizontal at which the material will stand without slipping. The batters corresponding to the angles of repose of the commonest materials are given below :—

	A		B		A		B
Rock	between 0	:	1	and	1		1
Gravel ..					0·9	:	1
Dry Sand ..					1·3	:	1
Compact earth ..	between 1	:	1	and	1·5	:	1
Well drained clay	between 1	:	1	and	1·5	:	1
Wet clay ..	between 2·5	:	1	and	4	:	1
Peat	between 1	:	1	and	4	:	1

Fig. 1 shews how these batters are measured.

The usual slope of railway banks is 1½ to 1, and the land purchased for the construction of a railway is generally of sufficient width at any place to accommodate this slope.

When, however, it is not possible to obtain sufficient width, the sides of cuttings are supported by retaining walls of brick, masonry, or concrete, and, in towns, where the rail level is required to be above the general ground level, the railway is usually carried on brick, or masonry arches.

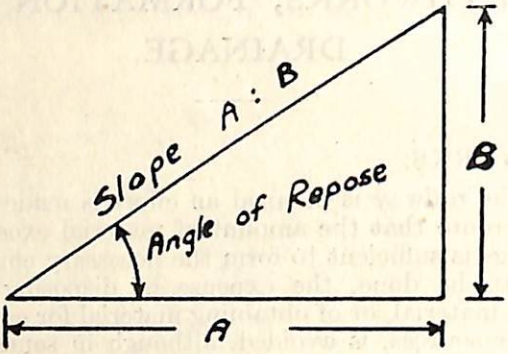


FIG. 1. MEASUREMENT OF SLOPES.

From the table of angles of repose on p. 7 it will be seen that with a clay bank, a slope which is quite suitable when the material is dry is far from stable when the material is wet. It is thus essential that clay slopes should be well drained as wet clay will slip until it reaches its angle of repose. The method of dealing with slips is dealt with on p. 125 *et seq.*

The permanent way staff is occasionally called upon to carry out small earthworks and the following points should receive careful attention :—

Tipping.

1. No heavy material should be tipped on the top of an embankment, without authority from the Engineer, as, if the embankment is not stable, such tipping might force the material at the toe of the slope outwards.

2. Care should be taken to see that no material is tipped over a watercourse, even though no water may be flowing at the time. Information should be obtained as to the maximum flow that has been known in the watercourse, and pipes sufficient to take this should be provided in the bed of the watercourse before the tipping is done.

3. Heavy material should not be tipped over a culvert or bridge, without authority from the Engineer, as the structure might not be sufficiently strong to take the extra weight. This applies particularly to structures such as the parapet walls of under bridges which may be pushed over by heavy material being tipped against them.

4. No material should be tipped against a fence, as it might push the fence over, and in the case of a wooden fence lead to the decay of the wood.

5. Tipping earth to any appreciable depth round the trunk of a tree, a hedge or a shrub will in time lead to the death of the plant.

Excavation.

1. Excavation should not be done close to any structure such as a building, a bridge abutment, a wing wall, or a retaining wall, except under instructions from the Engineer, as such excavation might weaken the foundations of the structure if they are shallow. It is generally necessary in such cases to support the foundations when the excavation is carried out.

2. No excavation should be done close to the top edge of an embankment, as this might form a pocket for water which would probably seep through the bank and so possibly cause a slip.

3. Care should be taken before any excavation is carried out to ascertain whether there are any railway or public service mains, such as electric power cables, gas or water mains, or drains, that are likely to be met with in the course of the work. Serious inconveniences to the users of these services are caused by any damage to the mains, and occasionally there is a risk of personal injury to the men working.

FORMATION.

The basic principle of the design of railway formations is that the very intense bearing pressure of the wheels on the rail, which may be as high as 20 tons per square inch, must be distributed over a sufficient area of the comparatively soft natural ground underneath to ensure that there will be no permanent deformation.

With the bull-head rail which is almost universal in Great Britain the load is transmitted by the rails first to the cast iron chairs. These bear on a softer material, the timber of the sleepers, and, therefore, have a base large enough to reduce the pressure to not more than about 400 lb. per sq. in. With flat-bottom rail on lines designed only for light traffic, the load is transmitted to the sleeper directly by the broad bottom flange, while on the heavily loaded lines, soleplates are interposed to give the required area for bearing on the timber, unless hardwood sleepers are used.

The sleepers in turn bear on that portion of the ballast which has been firmly packed, the pressure now being in the neighbourhood of 150 lb. per sq. in. The safe bearing pressure on most soils is, however, much lower than this, being often below 20 lb per sq. in. and it is the function of the bottom ballast to disperse the load over such an area that the safe pressure is not exceeded.

The portion of ballast which may be regarded as effective in carrying the load is that forming an imaginary pyramid under the load, the sides of which slope at approximately 1 : 2 as shewn on Fig. 2. From this drawing it will be apparent that the deeper the ballast is, the less the intensity of the pressure on the soil becomes. If the ballast is shallow the tendency is for the ground to be depressed under each sleeper, and if the soil is of a plastic nature, such as wet clay, it will be forced outwards and will rise in the spaces between the sleepers, whence it will work into the ballast in the form of a slurry as the sleepers " pump " up and down under traffic.

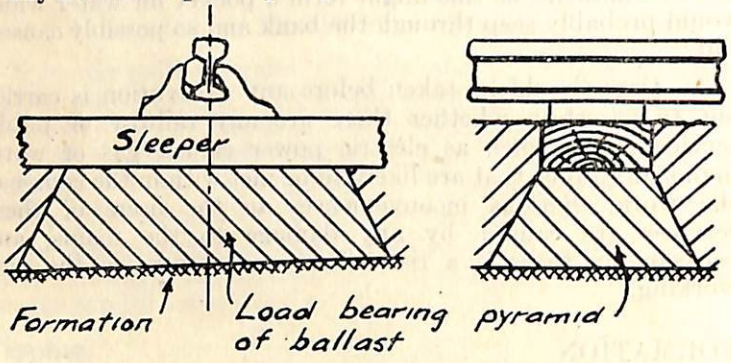


FIG. 2. LOAD ON FORMATION.

Most soils have a lower safe bearing pressure when saturated with water than when dry. It is, therefore, important that the " formation ", the surface of the ground upon which the permanent way rests, should be well drained. In normal cases good drainage may be obtained by giving a cross-fall, of between 1 in 45 and 1 in 20 from the centre of the formation towards the cesses. Water cannot drain away properly from a formation which has become furrowed and pocketed, and in such cases it is necessary to take off the ballast, trim off the formation to a suitable cross-fall, and to put in an adequate depth of ballast.

Fig. 3 shews a typical cross section of a formation.

Great difficulty is often encountered where the formation is of soft clay with a low bearing capacity, and various methods are used for spreading the load and " blanketing " the clay.

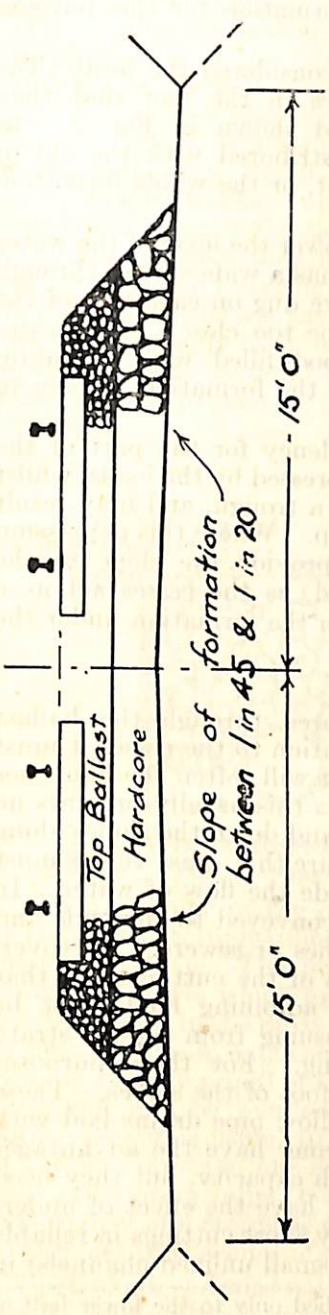


FIG. 3. TYPICAL CROSS SECTION OF FORMATION.

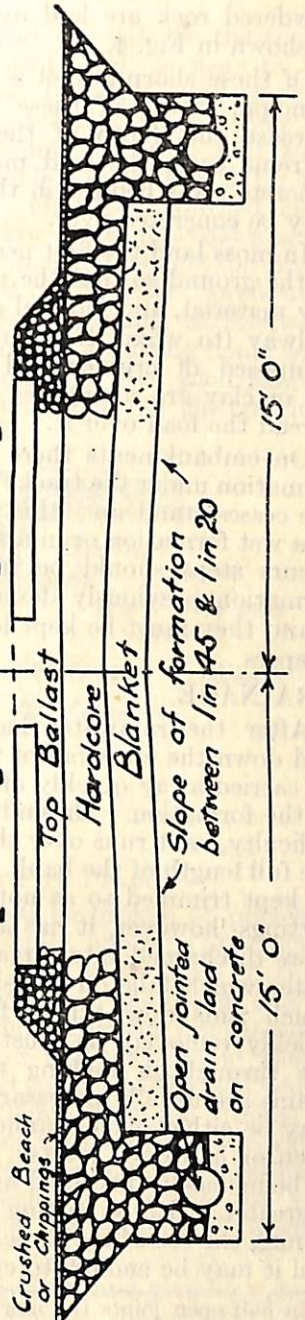


FIG. 4. CROSS SECTION OF BLANKETED FORMATION.

In many cases layers of gravel, sand, ashes, slag-dust, or powdered rock are laid over the formation for this purpose as shown in Fig. 4.

Of these sharp gravel is usually considered the best. The principal virtue of these layers lies in the fact that they increase the depth of the pyramid shown in Fig. 2. In extreme cases the load may be distributed with the aid of concrete slabs bedded in the blanket, or the whole formation may be concreted over.

In moss land the first need is to lower the level of the water in the ground so that the pyramid has a wide spread through dry material, and parallel ditches are dug on each side of the railway (to which they must not be too close). Mattresses composed of criss-crossed brushwood filled with mountain till or clay are sometimes laid over the formation to help to spread the load over it.

On embankments there is a tendency for the part of the formation under the tracks to be depressed by the loads, whilst the cesses stand up : this produces a trough, and may result in a wet formation or in a serious slip. Where this depression occurs steps should be taken to provide the slope to the formation previously described, and, as the cesses act as a drain, they must be kept lower than the formation under the sleepers.

DRAINAGE.

After the rainwater has percolated through the ballast and down the cross-fall of the formation to the cesses it must be carried away quickly otherwise it will soften the haunches of the formation. On embankments this usually presents no difficulty, as it runs over the edges and down the slopes along the full length of the bank. To ensure this, grass verges must be kept trimmed so as not to impede the flow of water. In cuttings, however, it has all to be conveyed to the ends and there discharged into streams, ditches or sewers. Moreover, water which falls on the side-slopes of the cuttings and that which runs down them from the adjoining land must be quickly removed, as must water issuing from porous strata cut through in making the cutting. For these purposes drains are usually necessary at the foot of the slopes. These may be either open channels or shallow pipe drains laid with open or half-open joints*. The former have the advantages of being easily inspected and of high capacity, but they need a greater width of cutting and may have the effect of undermining the toe of the slope. In very short cuttings in reliable soil it may be enough to cut grips (small unlined channels) in

* In half-open joints the mortar is applied only to the lower half of the pipe socket when making a joint.

the cess. Drains, channels and grips must have a good outlet at their lower end.

Pipe drains are laid in a trench, at a depth (to the top of the pipe) of 2′ 6″ to 3′ 0″ below rail level, as near to the haunches of the ballast as possible. In bad ground, such as silt, peat or soft clay it may be necessary to set them on concrete, which is haunched up round them to half their height as shewn in Fig. 5. The trench is filled in with broken stone, beach, bricks, rubble, large clinker or burned clay, (care being taken in the case of shallow drains to avoid placing large stones where they may be punched through the pipe). The pipes should never be less than 6 in. diameter ; preferably they should not be less than 9 in. Second quality earthenware pipes are normally used, but experiments are being made with pipes of porous material, which appear to give good results. They should be laid to a fall, preferably not flatter than 1 in 150.

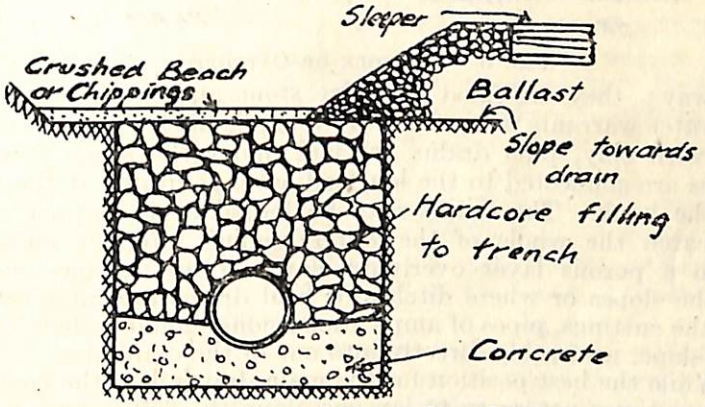


Fig. 5. Open Jointed Pipe Drain.

The continuity of the drain should be broken at intervals of about 100 ft. by manholes or catchpits, one type of which is shewn in Fig. 6. The purpose of these is to catch in their sumps the solids which find their way into the drain, and to provide access to the pipes for rodding. They are not intended to act as gullies to catch surface water, and they should, therefore, be slightly proud of the finished surface of the cess where they will not be overlooked. Where there are drains in both cesses it is useful to set the manholes on the two sides of the line opposite one another and to put in an occasional cross-connecting pipe between them, to provide for the eventuality of a stoppage on one side. It is useful to provide weep holes in the sides of manholes.

Open channel drains are frequently used and give very good results, especially where there are springs in the cutting. One

advantage they have over pipe drains is that they can be kept clear of debris more easily, and another is that the need for manholes is eliminated. Precast concrete channel 'U' shaped units with weep holes in the side have been widely used and give good results.

If the slopes of a cutting are wet, trenches may be dug in them at intervals of about 30 feet at right angles to the

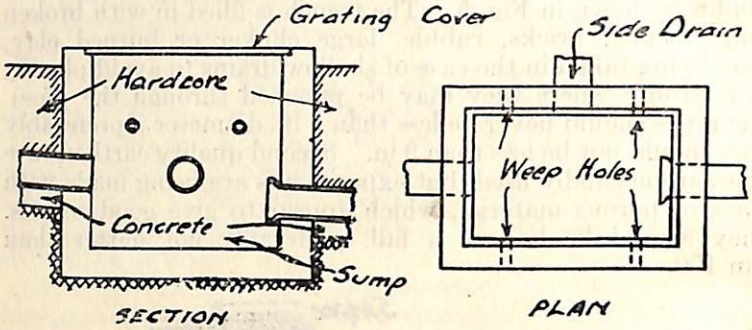


FIG. 6. MANHOLE OR CATCHPIT.

railway; they are filled with dry stone and, if the amount of water warrants it or if the dry stone is likely to be choked up with clay, pipe drains are laid under the stone. Such pipes are connected to the longitudinal pipe drains at the toe of the bank. The drains may be forked at the upper end to catch the whole of the water seeping into the cutting from a porous layer overlying clay. Where springs occur in the slopes or where ditches or field drains are intersected by the cuttings, pipes of ample dimensions should be led down the slope, preferably directly into one of the manholes.

While the best position for the main drains is in the cess, it is sometimes necessary to lay one along the 6 ft. way, as for example, between station platforms. If such a position is adopted the crossfall of the formation must be towards the drain. In stations the drainage of the platforms and roofs is sometimes carried to the drain in the 6 ft. way, passing under the tracks. Where this is done, and indeed where any pipe passes under the railway it must be deep enough to avoid interference with the functions of the ballast and to avoid the risk of its being broken. Station roof drains should have as much fall as possible, as they are very liable to be blocked with ashes. In marshalling yards and where there are four or more tracks, a drain is commonly required in alternate spaces between tracks, the formation being graded accordingly. In tunnels the usual position is under the 6 ft. way, and, if there is an invert, the drain may be constructed directly upon it, taking the form of a longitudinal culvert if the amount of water justifies it.

CHAPTER II.

PERMANENT WAY MATERIALS— PLAIN LINE.

RAILS.

The section of rail in general use on British Railways is the Bull head section, and rails are described by the weight in pounds of one yard of the rail.

The weight per yard varies between 60 lb. and 100 lb., advancing in units of 5 lb. per yard. The dimensions of the cross sections of the rails of each weight are laid down by the British Standards Institution, and these are given in Table 6 in the Appendix.

The sections marked ' R ' in the table were revised in 1922.

The full description of any rail is given by the weight per yd. followed by the letters B.S.(R), which stand for " British Standard (Revised) ", for the sections which were revised in 1922, or B.S. (British Standard) for those sections that were not revised.

The most common section in use in this country weighs 95 lb. per yd. and is known as the " 95 lb. B.S.(R) Bull head rail ". The words " Bull head " are not usually included, and where a rail is described by its weight alone it is always taken to be a Bull head rail.

Some branch lines with only light traffic are laid with the 85 lb. B.S.(R) Bull head rail, but, as described elsewhere in this book, the most usual way of dealing with such lines is to lay them with serviceable 95 lb. rails which have been removed from main lines, owing to the reduction in cross sectional area due to wear rendering them no longer suitable for heavy, high speed traffic.

Many old non-standard section rails, too numerous to describe in detail, are still in use on branch lines, but these are rapidly being replaced by standard section rails.

Until a few years ago the usual length of rails was 45 ft. though there are still a number of 30 ft. and shorter rails in use. The standard length is now 60 ft., and 90 ft. rails are coming into favour on some railways.

In some cases, generally for use in tunnels, two or three 60 ft. rails are welded together to form 120 ft. or 180 ft. rails, but special loading and unloading appliances are necessary with these.

The capacity of rails to withstand wear and shock has been the subject of careful study in the past few years. The steel generally used for rails may be either "higher carbon" or "medium manganese" steel.

In higher carbon steel the percentage of carbon varies between 0·45 and 0·65, and the percentage of manganese must not exceed 0·90.

In medium manganese steel the percentage of carbon varies between 0·40 and 0·60, and the percentage of manganese varies between 0·90 and 1·20.

The above percentages vary with the method of manufacture of the steel, and are the upper and lower limits for rail steel.

Steel also contains small amounts of silicon, phosphorus, and sulphur, and the percentage of these, and of manganese, in steel are not permitted by the British Standard Specification for carbon rail steel to exceed a fixed amount.

Experiments are continually being made to produce steel alloys which will have a greater resistance to wear by abrasion, and corrosion, and yet be sufficiently tough to withstand shocks. The most success to date has been obtained with an alloy of steel containing between 12 and 14 per cent. of manganese. This is known as a manganese alloy steel, and, though the cost is more than 5 times that of ordinary steel, its greatly increased resistance to wear makes its use an economical proposition in places such as very busy junctions, where with ordinary steel, the switches and crossings would have to be renewed every few months.

The great hardness makes it very difficult to cut and drill on site, and therefore very special care must be taken in measuring switches and crossings for renewal in manganese steel, in order that the rails may be cut and drilled exactly in the manufacturer's yard before being sent out to the work.

An American development of this is to use cast manganese alloy steel inserts for the parts of crossings which get the most wear, such as the parts of the wing rails near the nose, and the nose itself, and to make the remainder of ordinary steel rail. These, however, require careful maintenance to ensure that the inserts fit tightly to the remaining parts of the crossing.

In places where the rails are subject to the action of chemical fumes or water, such as in tunnels or near water troughs, rails containing between 0·25 and 0·30 per cent. of copper have been tried, and it is claimed that this steel has a greater resistance to corrosion than ordinary steel.

Improvements in the control of the cooling of rails in the steelworks have resulted in an improvement in the wearing

qualities of the rails. The rails are cooled in special ovens, patented by Messrs. Sandberg, and the same firm has carried the control of cooling a stage further by introducing the process known as the " Sandberg Sorbitising " process. In this the head of the rail after rolling is quenched suddenly by spraying cold water on to it and the rail is then cooled in an oven. This toughens the steel in the head for a depth of $\frac{1}{2}$", and does not alter the hardness of the remainder of the section. Thus the part of the rail which has to withstand abrasion is hardened, whilst the capacity of the rail to withstand shock is not lessened.

For many years a type of rail known as " flat bottom rail " has been occasionally used on swing, or bascule bridges, and in similar places, where there is not sufficient depth for Bull headed rails and chairs.

Experiments are now being made in this country with flat bottomed rail for main line track, similar to the track used generally on the Continent and in America.

With the British Standard Flat Bottomed Rails, details of which are given in the Table 7 in the Appendix, the width of the bottom flange is nearly equal to the overall depth of the rail.

The bottom flange is not so thick as the head, and, therefore, the ratio of the surface area of the foot to the volume of metal in the foot is greater than that in the head of the rail.

With normal methods of cooling rails as they come from the rolling mill, the bottom flange, therefore, cools more rapidly than the head, and this leads to cooling stresses in the rail which may cause internal fissures. In frosty weather these internal fissures may cause the rail to break and great difficulty has been experienced with this on many Continental Railways.

A detector car known as the ' Sperry Rail Detector ' is used to discover rails in the track which have these fissures. The car is run over the road and by means of instruments working on an electrical system, the rails which have fissures are located, and they can then be changed before they break.

CHECK RAILS.

A Ministry of Transport rule requires that all curves with a radius of 10 chains or less must be provided with a check rail fitted to the inside rail of the curve. In some cases curves of greater radius than 10 chains are provided with check rails.

As explained in the Chapter on " Curves ", when a vehicle is on a curve the wheels on the high rail tend to climb up the rail head. The function of the check rail is to make this impossible as the backs of the wheels on the low rail side bear

against the check rail. In order that this may be so, the bearing edge of the check rail must be placed at a distance from the running edge of the high rail equal to the distance between the backs of a pair of wheels plus the effective thickness of one flange, as shewn in Figure 7.

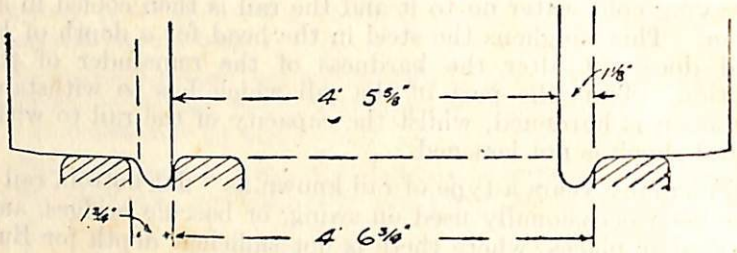


FIG. 7. FLANGEWAY CLEARANCE.

From this it will be seen that for track of standard 4′ 8½″ gauge this distance is 4′ 6¾″, and the flangeway clearance between the bearing edge of the check rail, and the running edge of the low rail, is 1¾″.

At the beginning and end of a check rail, the rail is curved to give a smooth entry, and, to avoid the wheel flanges receiving a shock when coming into contact with the rail, the flangeway at the end of a check rail should be widened to 3½″. The old method of doing this was to bend the rail with a crow, but this gave unsatisfactory results as the entrance was not gradual. The usual method of doing this now is to make the first and last chairs on a check rail to give a slightly wider flangeway than the standard, and also to make the flangeway increase slightly in the length of the rail seating on these chairs.

Thus the two end chairs are not interchangeable as they are of opposite hand (See p. 30). The free end of the rail is crowed slightly with this method as well.

A further development is the use of more special chairs at the entrance end, so designed that the flangeway decreases from the entrance to the point where the standard flangeway clearance of 1¾″ is obtained at a rate of 1 in 100.

Occasionally on very sharp curves the gauge is widened to allow engines with a long rigid wheelbase to pass round the curve more freely. In such cases the check flangeway clearance must be increased by the same amount as the gauge is widened in order to maintain the dimension 4′ 6¾″.

Check rails are also inserted in point and crossing work on the rail of any track where a crossing lies on the opposite rail. The check rail spans a certain distance in front of, and

behind the crossing, the length depending on the angle of the crossing. The object of these check rails is to ensure that the wheel passing over the crossing takes the correct side of the crossing nose.

If the flangeway clearance is more than it should be the wheel flange may strike the nose of the crossing. If it is less than it should be the wheel flange is liable to strike the check rail.

The inside rails of turnouts are also checked occasionally. The check rail must be stopped short before the switches at a point where the space between the stock rail and switch rail is just equal to the standard entrance flangeway of $3\frac{1}{2}''$ plus the width of the end of the check rail, which is usually slightly pointed.

In special cases the check rail is planed to a point, and the check rail can then be carried nearer to the switches. The planed end of the check rail is bolted to the switch rail.

Check rails are also inserted at level, accommodation, and staff crossings, and also where the space between the rails is required to be paved, such as in tracks on a quayside. The reason for this is, that as in these cases there are obstructions in the four foot which might become foul of wheels of stock, it is necessary to provide a flangeway for the wheels. The usual practice is to make the flangeway 2 in. wide in such cases.

RAIL JOINTS.

The two main types of rail joints are the "suspended" joint and the "supported" joint.

In the "suspended" joint the rail ends project beyond the bearings and are held together by a pair of fishplates. In the "supported" joint the rail ends are carried in a special joint chair, either with or without fishplates, on a joint sleeper. The rail ends are bolted to the jaw of the special chair.

The "suspended" joint is the type generally used with Bull head rails, and an elevation of such a joint is given in Fig. 8.

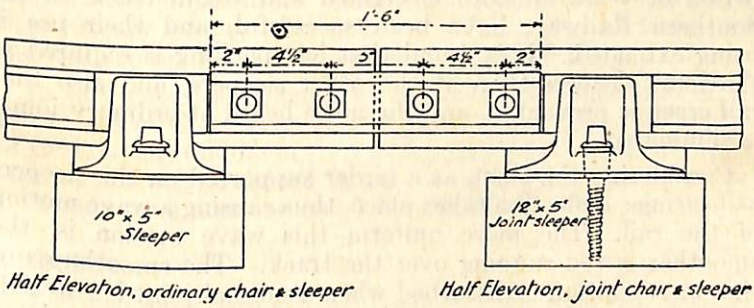


FIG. 8. ELEVATION OF RAIL JOINT.

The ideal rail joint would respond to the load of traffic in the same way as a rail, that is it would have the same strength, stiffness, and flexibility.

In practice the joint has to prevent transverse, and undue vertical movement of the rail ends, and at the same time to allow the longitudinal movement of the rails due to their expansion and contraction caused by variations in temperature.

Many experiments have been made to find an ideal type of joint, but although joints have been designed which were better in some respects than the normal, they have generally been intricate or costly to produce.

A new joint however, was designed by Mr. George Ellson, when Chief Engineer, Southern Railway, which is simple in construction, and in which the full strength of the rail is developed at the gap. The joint also provides a continuous bearing for wheels over the gap so that the knocking or pounding which always occurs at an ordinary joint is eliminated. The design is applicable to bull head and flat bottom rails.

The ends of the rails to be joined are cut for a short length on the outside of the rail to form a housing for an angle bracket which forms the outer fishplate. The top edge of this bracket is flush with the top of the rail except for a slight chamfering at the ends. Fishbolts are fitted through the vertical leg of the angle, through the rails, and through a standard fishplate on the 4-ft. side of the rail.

The rails and angle bracket rest on a cast iron baseplate supported on the joint sleepers which are 4″ apart. On the outside of the rail the bracket and baseplate are secured by a through bolt to each joint sleeper, and on the four foot side the baseplate is coach screwed to each joint sleeper.

Tests of these joints under heavy, high speed traffic over a period of years on both electrified and steam track on the Southern Railway, have been successful, and their use is being extended. It is found that less packing is required at the joint sleepers than at the other sleepers, and also that rail creep is prevented, and the noise heard at ordinary joints is eliminated.

Considering the track as a girder supported on the sleepers as bearings, deflection takes place, thus causing a wave motion of the rail. The more uniform this wave motion is, the smoother is the running over the track. The smoothness of this wave motion is disturbed when a normal joint is reached, and the disturbance is seriously increased when the joint

becomes worn. It has been experimentally shewn that as soon as the slightest wear takes place on the fishing surfaces of the plates as shewn in Figure 9, the trailing rail of the joint deflects under the load and the wheel strikes the end of the leading rail at " A ", jumps a small distance, and hits the leading rail again a little way from the joint at " B " (Fig. 9). An inspection of the track will reveal that this actually takes place.

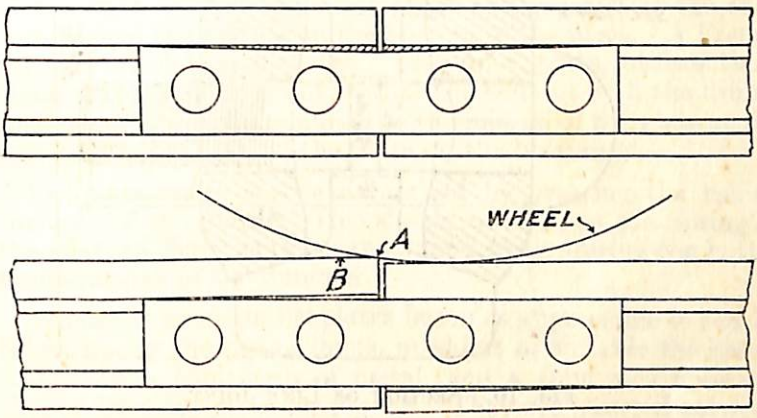


FIG. 9. WEAR ON RAIL JOINT.

It will be seen that these blows increase the wear on the fishplates, thus leading to heavier blows from the wheels, and so the action is rapidly progressive, resulting in time in the crippling of the rail ends if steps are not taken to remedy the trouble. The necessity for keeping the joints in good condition will be readily appreciated. In addition the packing of joint sleepers requires special attention, as these sleepers receive a series of hammer blows as the wheels pass over the joint as shewn in Fig. 9. In order to give greater support to the track at the joints, special joint chairs and sleepers are often used. The joint sleepers are wider than the ordinary sleepers, being 12 in. wide instead of 10 in., and the joint chairs have a wider base and rail seating.

In any case the spacing of the sleepers either side of the joint, and of those near to the joint, is less than the spacing of those in the middle of the rail length. The standard sleeper spacing for any standard length of rail is laid down by each Company, and must be carefully adhered to.

Fishplates.

The fishplates support the rails by means of the wedging action between the fishing surfaces as will be seen by reference

to Fig. 10. The angles of the fishing surfaces for the B.S. rail and fishplate are 20 degrees.

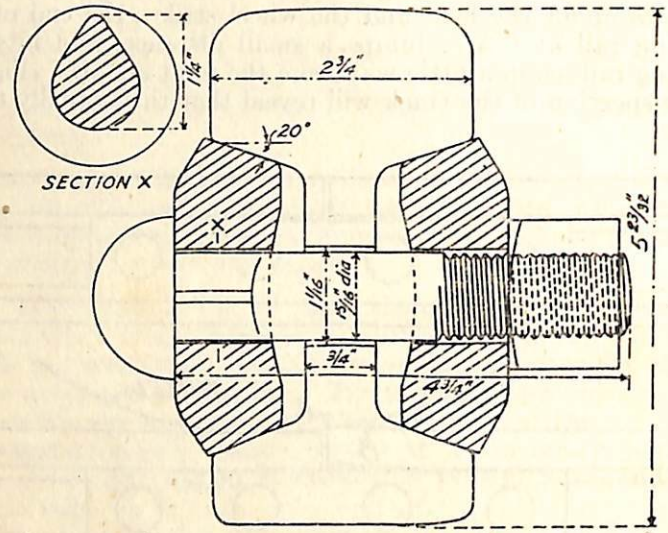


Fig. 10. Section of Line Joint.

The standard 18″ fishplate has four pear shaped holes to take the fishbolts, the pear shape accommodating the similarly shaped neck of the fishbolt, and the point of the pear being nearer to the rail end as shewn in Fig. 11. This pear shape ensures that the fishbolts do not turn when the nut is tightened. The standard fishbolt for B.S. track is shewn in Fig. 12.

Fig. 11. Fishplate.

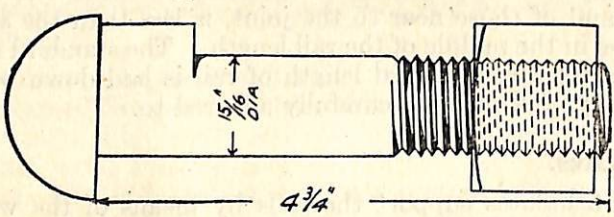


Fig. 12. Fishbolt.

In order that the joint sleepers may be brought closer together, and so give a more rigid support to the joint, fishplates 9″ long are now extensively used. On the Southern Railway it is now the practice to use fishplates 11½″ long, in order to protect the negative traction bond in the electrified areas. Both 9″ and 11½″ fishplates have two fishbolt holes.

The hatched area on Fig. 9 shews the manner in which fishplate wear occurs. It is greatest on the middle and least at the ends on the top of the plate, and greatest at the ends and least in the middle on the bottom of the plate. A French type of fishplate, called the " Chevron " plate, utilises these facts, and the plate is cut so that the contact with the fishing surfaces of the rail is confined to the middle of the plate at the top, and to the ends of the plate on the bottom.

Fishplate wear can be minimised by greasing the fishing surfaces of the plates. This should be done in the Spring of the year, so that the rails can expand freely during the hotter temperatures of the Summer.

When the wear on fishplates becomes appreciable it can be taken up by the use of liners, or shims of suitable thickness. A liner is a thin strip of metal, and a shim is a specially shaped liner, as shewn in Fig. 13. They are inserted between the top of fishplate and the underside of the rail head. Shims give better results than plain liners, as they are shaped to the actual form of the worn fishplate, being thicker in the centre than at the ends.

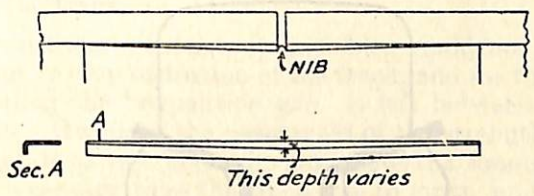


FIG. 13. JOINT SHIMS.

Care must be taken in using shims, however, as they are made in varying thicknesses, and the use of too thick a shim will result in a high joint and the risk of the fishplate being broken.

Occasionally a little nib forms on the top of worn fishplates as shewn in Fig. 13 and this must be removed before a liner or a shim is used.

Worn fishplates are now given a further life by a method originated in Germany, and fishplates treated thus are called " reconditioned ".

A small groove is pressed along the inside of the plates, thus forcing the metal to the edges and so increasing the depth of the plates.

When joining up rails of different sections, and also rails of the same nominal section which have worn by different amounts, it is necessary to use cranked or joggled fishplates as shewn in Fig. 14. Where the widths of the rails to be joined are different, the plates have to be side cranked and used in pairs as shewn in Fig. 14.

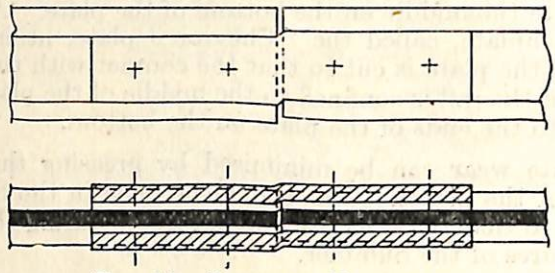


FIG. 14. JUNCTION FISHPLATES.

These special plates are also known as junction plates, and are made to fit all cases that occur in practice.

Insulated Joints.

At the ends of a length of track carrying a track circuit, it is necessary to insulate electrically the track circuited section from the track on either side. This is done by inserting

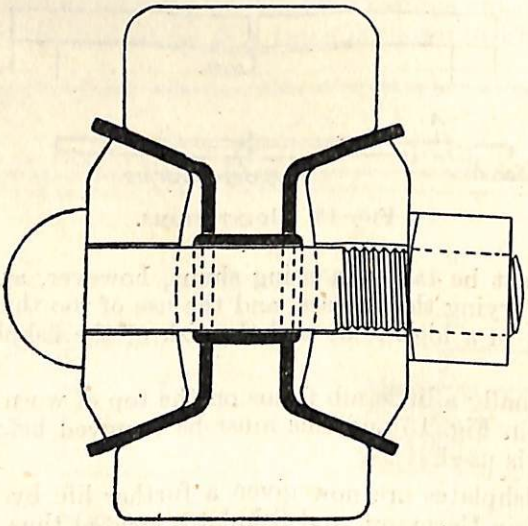


FIG. 15. INSULATED RAIL JOINT.

fibre packing between the fishplates and rails, between the fishbolts and the rails, and between the rail ends. A typical section of an insulated joint is shewn in Fig. 15.

Proprietary insulating fishplates made of compressed wood, and known as the " Permali " fishplates are now being used in considerable numbers.

Expansion Allowance.

All materials that are not rigidly fixed alter in size under variations in temperature, the amount of expansion or contraction depending on the amount of change in temperature and the size of the piece of material.

A steel rail free to expand and contract will expand $\frac{1}{150,000}$ of its length for each degree Fahrenheit increase in temperature and decrease the same amount for each degree Fahrenheit fall in temperature. (The temperature at which scientific measurement of lengths is made is 62°F). This means that a 60 ft. rail would alter about $\frac{1}{2}$" in length between summer and winter.

If railway lines were laid with continuous rails, increases in temperature would tend to cause the track to move sideways, *i.e.* ' buckle ', or to lift off the formation. The tendency of the track to buckle is resisted by the strength of the track and the friction of the sleepers on the ballast and the ballast at the sleeper ends, and the tendency to lift is resisted by the weight of the track.

These resistances, though appreciable, would not generally be sufficient to stop distortion of the track, and for this reason, a space called the ' expansion gap ' is left between the ends of the rails. Owing to the resistances of the strength of track and ballast it is not necessary to allow the amount which would be necessary were the track free to move, and it is also found that it is not necessary to increase the expansion gap in proportion to the length of the rails, *i.e.*, 180 ft. rails do not need four times the expansion gap that 45 ft. rails need.

The resistance to longitudinal movement of the track afforded by the keys and ballast also plays an important part in stabilising the track, and when long welded rails are used only a few sleepers at the ends of the rails normally move under the effects of expansion and contraction of the rail. The rest of the rail develops an evenly distributed compressive stress, which does not depend on the length of the rail, but which varies with the temperature, and buckling is prevented by the ballasting.

In tunnels the variation in temperature is usually less than in the open, and the expansion allowance may be considerably reduced except for three or four joints at the ends where the normal allowance should be given.

In some tunnels rails are being welded together to form a continuous rail, or a series of long rails. In the latter case it is usual to allow an expansion gap of 1/16″, except towards the ends of the tunnel, where the normal expansion gaps are provided.

When new rails are being laid in it is essential that the correct expansion gap is allowed at the ends, the amount required depending on the temperature of the rails whilst the work is in progress.

Average amounts of gap allowed for various temperatures, for both 45 ft. and 60 ft. rails are given in the following table, although each Railway issues its own instructions on this subject. Special instructions are also issued in each case where rails longer than 60 ft. are used.

Temperature of rails during laying.	Expansion gap required.
Above 75°F. ..	$\frac{1}{8}$″
Between 75°F. and 40°F. ..	$\frac{1}{4}$″
Below 40°F. ..	$\frac{3}{8}$″

Expansion irons of the required thickness, which slip over the ends of the rails, are placed in position when the rails are laid in. The rails are then pulled up tight against these and the keys driven. Care must be taken to see that the irons are all collected when the work is completed.

To simplify the Inspectors' work in deciding what thickness expansion irons are required, a thermometer had been devised which gives the gap required, by direct reading of a mercury column on a scale.

The thermometer is fixed in a piece of steel, and the whole should be laid in the web of a rail sometime before the rail is to be laid in.

SLEEPERS.

Sleepers perform the duties of holding the rails to correct gauge, and distributing to the ballast the load imposed on the rails by traffic.

They are generally made of timber, steel, cast iron or concrete. As the chief qualities required are a certain amount of flexibility combined with toughness and resistance to shock, timber and steel are the most common materials. Cast iron and concrete do not possess these qualities to a great degree, although in some tropical countries cast iron 'pot' sleepers are used with success. These consist of two bowl shaped portions, one of which supports each rail, with a steel rod connecting them to maintain gauge. The use of concrete sleepers is also being extended in this country.

Wooden Sleepers.

In England wooden sleepers are in almost universal use as they are easily available, and, when impregnated with creosote have a good life. In addition they can be used where track circuits are in operation, whereas with steel sleepers the electric currents would pass through them to earth.

The most common woods in use for sleepers are Baltic Redwood and Douglas Fir. Both of these are soft-woods and are readily impregnated with creosote. A number of tropical hard-woods, such as Jarrah, have been used for sleepers in this country, but they are more costly than soft-woods.

The process of creosoting may be done in one of two ways. The untreated sleepers may be immersed in a bath of creosote and left in until they are judged to have absorbed sufficient creosote. This method is, of course, haphazard, and the following is the one in general use at the moment. A batch of sleepers which have been dried in stacks is placed in an air-tight steel chamber from which the air is then exhausted. This opens the cells of the wood. Creosote is then pumped into the chamber under pressure, which forces in into the cells of the wood. The amounts of creosote absorbed by different sleepers vary, a hard sleeper taking less than a soft one. On the average a Baltic Redwood sleeper absorbs 3 gallons, whilst a Douglas Fir sleeper absorbs $1\frac{1}{2}$ gallons. In order to ensure that a sufficient quantity of creosote is injected the untreated sleepers may be incised before creosoting, by passing them between rollers covered with knife edge projections. These projections penetrate the wood and make it less resistant to creosote.

It is generally found that, except at the ends of sleepers the penetration is not very deep. For this reason if a sleeper has to be adzed on site, the cut should be painted with creosote.

With 4′ $8\frac{1}{2}$″ gauge the usual size of sleepers for plain track is 10″ × 5″ × 8′ 6″ long, although the sleepers adjacent to joints are frequently made 12″ × 5″ × 8′ 6″ long (*See* Fig. 8).

On some of the older types of track in this country the sleepers are 9′ 0″ long, and at times the joint sleepers were made 6″ thick, *i.e.* 1″ thicker than the middle sleepers.

On looking at the end of a sleeper, the rings which show the annual growth of the wood will be seen. It is common practice nowadays to lay the sleepers with the rings of the smallest radius downwards.

Steel Sleepers.

In tropical countries, where the rapid destruction of timber by insects renders the use of timber for sleepers uneconomic, steel sleepers are almost universal. Of recent years, large quantities of steel sleepers have been used in this country. In inland rural areas where they are not subject to attack by chemicals in the air, as they would be in industrial or seaside districts, they appear to be satisfactory. As mentioned previously they cannot be used where track circuits or automatic signalling are in operation, nor on electrified lines using the third rail system. The average life of steel sleepers cannot yet be given definitely though in favourable circumstances it would seem to be at least equal to that of wooden sleepers, and in addition the scrap value of the material is high.

The steel sleepers in most general use in this country are made of 5/16″ or $\frac{3}{8}$″ steel plate with beaded edges, pressed into the form of an inverted trough, the ends being closed to give a resistance to the track moving out of alignment.

There are various chair arrangements, however, and the following are the most common types :—

1. *Sandberg.* Steel trough with one central rib on top and two ribs underneath. The chairs are formed by pressing up pieces of the trough to form the key jaws, and a loose soleplate is provided as a rail seating.
2. *Unit Ebbw Vale.* Steel trough with pieces of the trough pressed up to form the rail jaws.
3. *G.K.N.* Steel trough with cast iron chairs cast on the troughs. There are four holes in the trough through which the molten metal flows during the casting of the chairs, thus forming heads on the underside.
4. *Dorman Long.* Steel trough to which chairs of special rolled section mild steel are electrically welded.
5. *Workington.* Steel trough to which chairs, bent and pressed from flat steel, are electrically welded.

When relaying track, which previously had wooden sleepers, with steel sleepers, it is necessary to provide extra ballast to a depth of about $4\frac{3}{4}$″ if the rail level is to be maintained at

the original height. It is found that small ballast gives the best results with steel sleepers, ½"-1" granite chippings being found very suitable.

Owing to the trough shape of steel sleepers it is found that sluing presents some difficulties. The sleepers tend to rise up on the mound of ballast inside the trough when being slued, and fall back to their old positions under traffic. For this reason care should be taken to see that the alignment of newly laid steel sleepered track is in good order before traffic runs over the track and consolidates the beds.

RAIL AND SLEEPER FASTENINGS.

Chairs.

Bull head rails are supported in chairs which are generally made of cast iron. The standard chair for 95 lb. rails, known as the 'S1' chair, is shewn in Fig. 16. The pressure of wheels on the rail is transferred to the chair over the area of the rail seating, and thence to the sleeper over the area of the chair base. There are three tapering holes in the base through which pass the coach screw fastening described later. The chair has two jaws and the web of the rail is held tight up against the inner jaw by a key which is driven in between the outer jaw and the rail.

For use at joints where 12" wide joint timbers are provided wider chairs are used, these being 10" wide instead of 8" as the 'S1'.

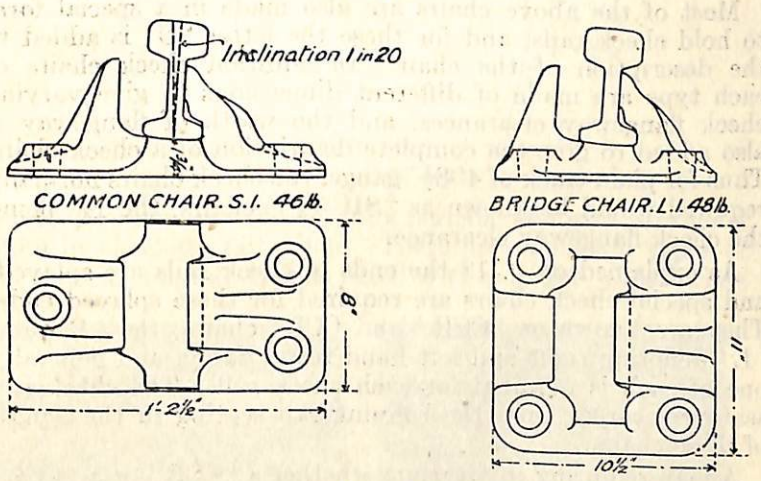


FIG. 16.

In places where the width of the chair seating is limited, such as on bridges with longitudinal timbers and in point and crossing work, chairs with a narrow base, known as

Bridge Chairs, are used. Fig. 16 shews one type of Bridge Chair known as the 'L1' chair. Another type of Bridge Chair known as the 'M1' chair is made, the base of which measures 10″ long and $8\frac{3}{4}$″ wide. The use of 'M1' chairs should be avoided where possible as, owing to the small area of the base, they are liable to cut into the sleepers. 'L1' and 'M1' chairs have four fastenings per chair.

The chair which has been the standard on the Great Western Railway for use with British Standard Rails for some time, and is now being used by some other Railways, differs from the 'S1' chair in a number of ways. The chair has only two fastenings of the 'through bolt' type (*See* p. 32). As explained on p. 33 this type of fastening has no thread in the timber of the sleepers, and the resistance to the spreading of gauge under load is helped by serrations or notches which are cast into the base of the chair. With some chairs of this type however, there are no serrations on the base of the chair, and the sleepers are not cut.

On high viaducts and bridges where the consequences of a derailment would be exceptionally serious, a safety device known as a 'guard rail' is occasionally fitted. The design of this varies on different Railways, but the general principle is that a line of old rails laid flat is provided parallel to, a few inches above, and on the outside of the cess rails of the tracks adjacent to the parapets. Special chairs are used which have an extension to support the guard rail.

Most of the above chairs are also made in a special form to hold check rails, and for these the letter 'C' is added to the description of the chair. In addition check chairs of each type are made of different dimensions to give varying check flangeway clearances, and the width of flangeway is also added to give the complete description of a check chair. Thus for plain track of 4′ $8\frac{1}{2}$″ gauge, the check chairs normally required would be known as 'S1C-$1\frac{3}{4}$″' chairs, the $1\frac{3}{4}$″ being the check flangeway clearance.

As explained on p. 18 the ends of check rails are splayed, and special check chairs are required for these splayed ends. They are known as 'CCR' and CCL' chairs, the 'R' and 'L' denoting right and left hand respectively, and generally one of each is required for each check rail. The check rail seating diverges from the running rail seating in the length of these chairs.

A man requiring to ascertain whether a 'CCR' or a 'CCL' chair is needed in any case should place himself so that the running rail which is checked is between him and the check rail. Then the splayed end on his right needs a 'CCR' chair, and that on his left a 'CCL'. If he requires to find

out whether a check chair is ' CCR ' or ' CCL ', he should place the chair so that the wider space between the running rail seating and check rail seating is towards him. (The running rail seating is parallel to the edges of the chair). Then if the check rail seating is on the right hand side the chair is a ' CCR ', and if on the left hand side, then the chair is a ' CCL '.

In most cases check chairs have four fastenings.

All chairs have letters embossed on them indicating the type, in the case of check chairs the flangeway clearance, the maker's initials, and the month and year of manufacture.

Keys.

Rails are held in chairs by keys. Oak or teak keys are still largely used, but steel keys are generally more satisfactory as they are less affected by climatic conditions, though they do tend to fall out during very cold weather. Wooden keys are liable to shrink during hot and dry weather, and thus their hold on the rails is weakened, and the tendency of rails to creep is not checked.

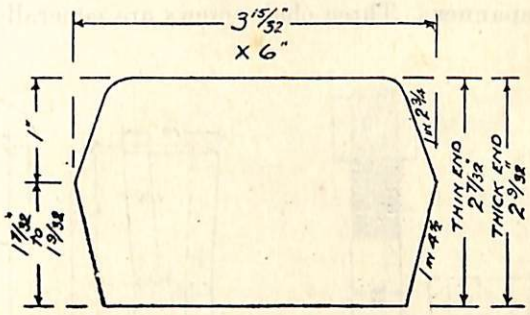


FIG. 17. OAK KEY.

Steel keys remain tight for long periods, and give very good results in checking rail creep. There are two main types of steel keys in use, one type is fitted with a wedge, which when

FIG. 18.

tightened gives the grip to the key, such as the Stuarts Key, and the other a one piece key, made of spring steel, such as the "Turplatt" or "Mills" Keys. Fig. 17 gives details of wooden keys, and Fig. 18 shews tracks fitted with both types of steel keys.

Keys of all types should be driven in the direction of running, except in the chairs on the leading end joint sleepers where the fishplates make it necessary to drive the keys in the opposite direction.

Chair Fastenings.

Chairs may be fastened to the sleepers by chair screws, through bolts, or treenails and spikes. The first two types have generally superseded the treenail and spike method. The chair screw, which is the British Standard fastening for Bull head rail, and the chair ferrule, which is always used with it, is shewn in Fig. 19. The ferrule is first driven into the screw hole in the chair, it being left projecting about a $\frac{1}{4}$" above the top of the hole. The screw is then tapped lightly into the bored hole in the sleeper for a small part of its length, and it is then screwed down firmly on to the ferrule by a box spanner. Three chair screws are generally used on a chair.

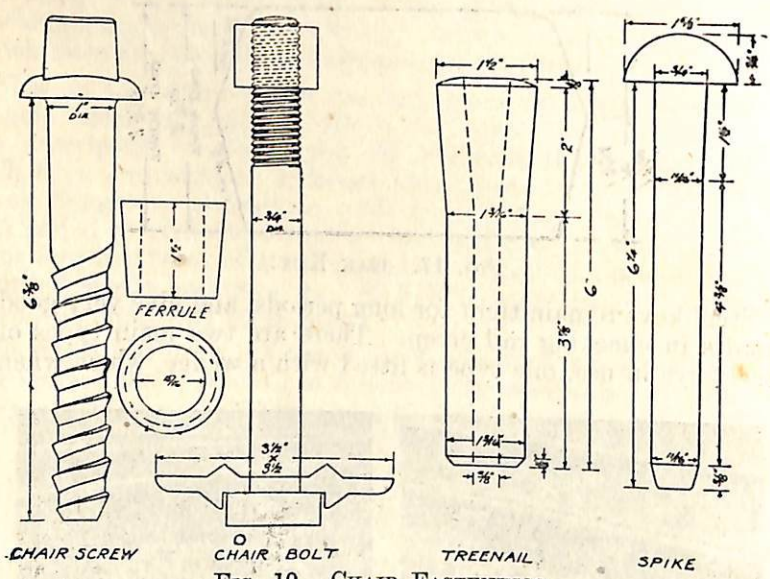


FIG. 19. CHAIR FASTENINGS.

The through bolt, or chair bolt, fastening which has been in constant use on the Great Western Railway for a long period with British Standard rails, and is now being used by

other Railways, is shewn in Fig. 19. It consists of a bolt and nut, and a washer plate, which has ridges which press into the underside of the sleeper and so hold the bolt firmly in position. The bolt passes completely through the sleeper and the nut is tightened down on to the top of the hole in the special chair described on p. 30. No ferrules are used with this type of chair fastening.

The treenail and spike fastening consists of two parts, the wooden treenail and metal spike, as shewn in Fig. 19. The treenail, which is a hollow cylinder of wood, is first driven through the holes in the chair into the sleeper. It should be driven in so that its top is flush with the top of the hole in the chair. The metal spike, which is slightly larger in diameter then the hole in the treenail, is then driven in through the treenail.

The through bolt gives a very rigid fastening for the following reasons :—

1. It does not depend for its strength on the resistance of the timber to crushing by the bolt, as its strength is obtained by the resistance to sliding of the base of the chair on the sleeper, and by the hold of the base plate on the underside of the sleeper.

2. It can easily be kept tight.

3. It has little tendency to split the sleepers.

It has certain disadvantages as follows :—

1. It consists of three parts, whereas the other types of fastening have only two parts. Against this, however, is the fact that only two fastenings are needed for each chair.

2. With chairs which have serrated bases it is necessary to cut the sleeper under the chair to fit the serrations. This makes it impossible to move this type of chair without destroying the benefit obtained from the serrations.

3. It is rather more difficult to remove a chair with through bolt fastenings than with other types of fastenings, as the head of the bolt is on the underside of the sleeper covered with ballast.

If kept tight and undisturbed the chair screw also gives a very rigid fastening. It depends for its strength on the friction between the base of the chair and the sleeper, and on the resistance of the sleeper to crushing by the screw. It is occasionally found that sleepers split along the grains cut by the screw. If the chair screw is removed and refixed a number of times, the thread which it cuts in the timber is liable to be destroyed. A new method of remedying this trouble, called

the "Metospir" method, has been introduced, which consists of inserting into the worn hole a metal strip shaped to the form of a spiral to form a new thread. A special tool is required for this.

Another method of dealing with worn screw holes in sleepers which gives good results is by putting some 'Philplug' (a plastic compound) in the screw hole. The screw can then be replaced and the 'Philplug' sets hard.

When a chair screw hole becomes worn the chair screw may be removed and replaced by a treenail and spike with satisfactory results.

The treenail and spike fastening depends for its strength on similar factors to the chair screw. When the fastening becomes worn it can easily be reconditioned by fitting a new treenail. It is not quite so rigid as the chair screw which can be tightened to hold the chair more firmly to the sleeper than is possible with a treenail and spike.

If it is necessary to move a chair on a sleeper as sometimes happens when the screw holes become worn, the old holes should be securely plugged either with wood, or one of the special compounds on the market, such as 'Philplug'.

FLAT BOTTOMED TRACK.

In this country flat bottomed track has been occasionally used in positions such as over engine pits, coaling stages, turntables, and sidings, and in places where it is not possible to obtain sufficient depth for chairs, but it has not generally been used in running lines.

Flat bottomed rails have a greater rigidity, weight for weight, than bull-headed rails, and the introduction of very high speed trains, which are causing more rapid wear of B.S. track, has led to experiments in this country with flat bottomed track in lines carrying express traffic, with the object of obtaining a more rigid track with only a small increase in cost.

The rail first used was the B.S. Flat-bottomed rail of 110 lbs. per yard section, but the experiments are also being made with a rail of 131 lbs. per yard, based on an American Standard section.

Flat bottomed rails are used generally on the Continent and in America, and many other countries, and where hardwood sleepers are used it has been the general practice to fasten the rails directly on to the sleepers by screws or spikes. Where hardwood sleepers are not available, and where the traffic is heavy it is usual to insert a rolled steel or cast iron baseplate between the rail and the sleeper. The fastening

of the rail to the baseplate may be utilised to fasten the baseplate to the sleeper, or alternatively separate fastenings may be used for each purpose.

The baseplates and fastenings now being tried on the L.M.S. are of four types, two being based on a German design, and two on an American.

In the German design the rail is held by clips, two of which are attached to each baseplate by bolts, one end of the clip bearing on the foot of the rail. The baseplate is fixed to the sleepers by screws similar to the chair screw, used for bull-head track. A poplar pad 3/16″ thick is placed between the rail and baseplate.

In the American design the rail is held by two mushroom headed screws per baseplate, 1/32″ clearance being allowed between the underside of the mushroom head and the top surface of the foot of the rail. With this type it has been found necessary to employ rail anchors. An alternative fixing to one of the American types is the ' Elastic Rail Spike. These spikes are made of a strip of $\frac{5}{8}$″ × $\frac{5}{16}$″ spring steel, folded at the centre, and the two halves laid together so that a $\frac{5}{8}$″ square results. The open ends are then bent over into a swan necked shape curve, and the closed end hammered out to a wedge shape to facilitate driving. The swan neck presses on the foot of the rail when the shank is driven into a pre-bored hole in the sleeper. The pressure obtained is sufficient to hold the baseplate, through which the spikes pass, firmly on the sleepers.

In order to avoid the necessity of manufacturing a considerable variety of junction fishplates to connect flat bottom track to bull head rails of varying types, and degrees of wear, a length of new bull head track is laid at each end of a length of flat bottom track. Only one type of flat bottom to bull head fishplate is then required, and the normal types of junction fishplates can be used at the ends of the length of new bull-head track.

The dimensions of British Standard Flat Bottom Railway Rails are given in Table 7 of the Appendix.

BALLAST.

Ballast is the name given to the material placed between the sleepers and the formation, and its functions are—

1. To distribute the load of traffic from the sleepers to the formation.
2. To permit of drainage of the track.

3. To prevent lateral movement of the track (by friction beneath the sleepers and by the weight at the sleeper ends).
4. To prevent longitudinal movement of the track.
5. To afford a convenient medium for packing the track to cross level and gradient.

On new tracks ballast is usually laid in two layers, called bottom ballast or 'hardcore' and top ballast, (*See* Fig. 3, p. 11). Bottom ballast chiefly performs functions 1 and 2 above, and consists of fairly large and hard stones measuring on an average 9″ in one direction, which are packed closely over the formation. Top ballast is then spread on top and performs functions 1, 2, 3, 4 and 5. The depth of ballast varies on different lines, but it may be stated that the deeper the ballast, the less will be the intensity of the load on the formation. (*See* p. 10).

A variety of materials are in use on different lines, as top ballast, according to the importance of the line, the proximity of the sources of supply of materials and the possibility of subsidence.

The qualities which must be possessed by good top ballast are :—

(1). Good bearing capacity.
(2). Good drainage capacity.
(3). High frictional resistance to movement of sleepers.
(4). Suitability for packing.

The first three qualities are fulfilled best by a hard, angular material which will lock together but which will not crush into dust. To satisfy the fourth requirement the material should pass a 2″ mesh sieve, while a proportion of smaller material is preferable.

The following are the more common materials is use as top ballast :—

Crushed Granite or Whinstone is the best ballast, as it is angular and almost indestructible. It is, however, expensive and is not quarried in South-East England.

Crushed Slag has some of the qualities of granite, though to a lesser degree, and for packing it is not quite so satisfactory. In the neighbourhood of ironworks its cost is lower than that of stone.

Crushed Limestone has the advantage of angularity and good drainage, but some limestones are liable to grind into dust,

which causes wear of journals and other moving parts of rolling stock.

Gravel or Beach is readily available in some parts of the country, but is not a good material for ballast, it being rounded and therefore liable to movement. Moreover it often contains dirt in which weeds can grow.

Crushed Flints may be regarded as intermediate between gravel and slag or granite.

Ashes make good packing material, but crush rapidly into dust, leading to bad drainage. They may contain chemicals injurious to steel sleepers. As they are readily obtainable from motive-power depots, they are economical for lifting in subsidence areas and may also be used in sidings.

LIFE OF PERMANENT WAY MATERIALS.

All the component parts of the track necessarily deteriorate with time, the rate of deterioration depending upon the situation, the nature of the traffic, and the standard of maintenance, Normally, the life of plain running line averages up to about 20 years. After this period the running line is relaid with new material, and the greater part of the displaced material, (*i.e.* that classed as "serviceable"), is re-used in sidings or on secondary lines. In some cases, however, the life of materials is decreased by local conditions, and often those conditions, by affecting one component more than another, necessitate partial renewal at frequent intervals.

The principal factors causing deterioration of materials are given below.

Rails.

(*a*) *Corrosion or Rusting.* Corrosion is caused, not by dampness, but by the acid gases dissolved in the film of moisture which frequently coats the rail. These gases are present everywhere in small quantities, but, in industrial areas and particularly in iron and steel districts, the atmosphere is rich in them, accelerating corrosion of rails. This condition is particularly marked in tunnels, and, in a poorly ventilated tunnel, it may be necessary to re-rail as frequently as every four years on this account alone. Rails subject to regular traffic corrode less rapidly than those on disused lines, as the dropping of oil, together with vibration tends to check corrosion.

(*b*) *Wear of rail table.* Even though the load may ride squarely on each rail, without any slipping, there is some mechanical abrasion of the bearing surface of the rail, owing to the slight roughness of the wheel tyres and the film of dust

which inevitably lies upon the rail. This mechanical effect may be enhanced by the formation of a very thin film of rust slurry in damp weather. Where traffic is very heavy, the amount may increase, though not by any means proportionately. On certain underground lines where, owing to the use of fibre brake blocks, the tyres, (and, hence, the rail heads) acquire a high polish, almost free from dust, vertical wear of the rails is reduced very considerably.

(*c*) *Battering of rail table.* As explained elsewhere, when an axle with two wheels rigidly attached to it traverses a curved track, one of the wheels must slip somewhat, owing to the fact that, although they have different distances to travel, they are both constrained to rotate at the same speed. This slip usually occurs most on the low rail, or inside rail of a curve, as at normal speeds the wheels on that side have a smaller grip on the rail. The effect of the slip is to make the metal forming the rail table flow outwards, and a thin flaky lip is pushed over the back or non-running edge of the rail. (*See* Fig. 83). This has the same effect as (*b*), in that it reduces the depth of the rail.

(*d*) *Side-cutting.* As explained in the Chapter on ' Curves ', the high rail of a curve has to withstand a heavy pressure from the wheels of vehicles travelling over the curve. This leads to the running edge of the high rail becoming worn or ' side-cut '.

The effect of designing rolling-stock with a low centre of gravity is that the pressure exerted by the wheel flange on the side of the rail-head in negotiating curves, is greater than with normal stock. For this reason, side-cutting is particularly prevalent on electrified lines worked by multiple-unit stock. This form of wear accordingly determines the life of rails on many electrified sections of line, as it proceeds with great rapidity, roughly proportional to the amount of traffic. Instances have been known of rails which have to be changed every six weeks on this account. Side-cutting is much reduced by fitting Oil Boxes to the high rails of curves. (*See* p. 112).

(*e*) *Crippling and battering of rail ends.* The impact of wheels on the running-on end of a rail causes the sharp arris of the rail-end to be hammered down, particularly if the fishplates do not fit tightly. Once started, this defect is progressive. Battering may also occur a few inches from the running-on end of the rail, where the wheels strike the rail again after being momentarily lifted by impact with the joint. Crippling, or permanent deflection of rail ends, occurs where the joint sleepers have been either slack or packed unduly hard. In both cases the rail would be subject to

overstress in bending, which would lead to ultimate failure. Wear also occurs on the fishing planes at joints, particularly if oiling of fishplates has been neglected.

If the wear on a rail is reasonably uniform, and it has not had to be previously condemned owing to crippling or undue wear at the joints, it is generally considered to be due for replacement when it has lost about 10 per cent. of its original weight. It then has a further use for secondary lines or sidings.

The life of serviceable rails when re-used in sidings and loops varies, not only according to the atmospheric conditions, but according to the amount of deterioration which can be permitted before condemnation. Twenty years is quoted as a rough average. Rails embedded in concrete or brick paving tend to last longer, unless the webs are weakened by corrosion at the surface of the paving.

Sleepers.

(*a*) *Decay.* Despite the preservative effect of creosote sleepers are attacked, after some years, by fungi which cause rot. Decay may begin where the edges of chairs have cut into the timber or it may spread from cracks. If the germs of decay were present before creosoting the heart may decay and the sleeper cave in on the underside. The commonest manifestations of decay are the loss of hold on the chair fastenings and the spreading of the gauge. The chairs gall into the timber, particularly on the outside, and the fastenings become visibly inclined towards the sleeper-ends.

(*b*) *Splitting.* Splitting of sleepers may result from the purely internal stresses in drying, particularly in underseasoned timber, but one of the chief causes is the effect of the chair fastenings in bursting the grain. The result is that the fastenings lose their grip, while decay follows the opening up of the uncreosoted heart to air and water. Small dogs with tapering spikes may be driven into sleepers, at or near the ends, to close up cracks, or metal cramps may be used.

(*c*) *Breaking.* Individual sleepers may break if they are end-bound, or centre bound.

The condition of sleepers cannot be fully ascertained while they are in the road, but cracking can be seen and decay probed for with a sharp spike, which should be applied particularly at the edges of the chairs. If the ballast shoulder is removed it may be seen whether the rings are separating. It is usual to take about ten consecutive sleepers out of the road in each quarter mile which is under consideration for renewal and to accept them as typical.

The life of sleepers of close-grained Baltic redwood is about 30 years, if well-seasoned. Of late years it has been necessary to use quicker growing timber, such as Douglas fir, and it is now not wise to count on a life of more than 15 years in the main line. Thus in rural areas the life of the sleepers is rather less than that of the rails. In sidings it is usually the condition of the sleepers which determines whether or not they are due for renewal.

Sleepers buried under brick paving last a very long time, but when once uncovered they rot very quickly.

Chairs, Fastenings, etc.

The only wear to which chairs are normally subjected is on the rail seats, where a mutual galling of rail and chair takes place. If this is serious, as it frequently is under level crossings, the section of the chairs may be reduced enough to cause them to break across.

Chairs in tunnels, however, are under conditions which favour rapid corrosion, and this frequently reaches such proportions that the chairs break. A careful watch must be kept for broken chairs in all tunnels.

Casual breakages also occur across the corners, and through the bolt holes. Derailments, of course, may cause wholesale breakages of chairs.

When steel keys are used, chairs may be broken through the key being driven too hard, but this should not occur if the instructions with regard to the driving of steel keys are carefully carried out.

The smaller parts of the track are all subject to deterioration. The chair fastenings may become bent, or may corrode, usually about the level of the chair base, and break off. The fishplates wear as shewn in Fig. 9, and with the tightening of the fishbolts, may become bent in plan. Wooden keys may shrink or split, whilst steel keys may lose their spring, and if of the wedge type, the wedge may become deformed.

MEASURING WEAR OF RAILS.

The direct method of obtaining the loss of weight of a rail is to lift it out of the road and to weigh it. This is done by means of a steelyard fitted with suitable clips and suspended from a tripod set up over the rail, which is first turned out of the chairs. For rails over 45-ft. long, two steelyards are used, suitably spaced, the weights recorded by each being added together.

While the rail is out of the road it is usual to take rubbings of its ends. A piece of thin paper is held over the rail-end and the outline marked by a cobbler's heel ball, a pencil, or the finger.

The time taken for the weighing and rubbings averages 15 minutes per rail, plus the time spent in waiting for possession of the road. 20 men (including flagmen) are required for the job.

Weighing being so cumbersome and costly, several profiling machines have been designed to give a profile of the rail, at an intermediate point, such profiles being preferable to rubbings of the ends, which are usually not representative of the whole rail. These machines may be classified into three groups: (1) those in which the Operator draws a tracing-point round the rail, the mechanism being arranged so as to cause a scribing point or pencil simultaneously to trace out a similar outline on a piece of paper or a blackened plate; (2) those in which a moulding of the profile is taken in a plastic material and (3) calipers. With any of these appliances it is essential that the rail be well cleaned of rust and scale before a profile is taken.

(1) The first group includes the Walker instrument, the Langley-Bayly instrument, and the Casella instrument. The Thornton instrument is of the same class, but gives the profile of the head only by a pantagraph gear.

(2) The moulding devices use plasticene, wax or lead strip. The one in commonest use is the Wood-Hill appliance, which consists of a hinged frame containing an aluminium centre made in two halves, the centre having hollows to enable the instrument to be fitted round any rail. The rail having been cleaned and dusted with French chalk, and the hollows lined with plasticene, the two leaves are clamped together round the rail, the plasticene being trimmed flush with the aluminium centres with a flat broad-bladed knife. The instrument is then removed from the rail by pulling out the hinge pin, unscrewing the side butterfly nuts, taking off the frame and then carefully separating the two halves of the aluminium mould, the plasticene being cut top and bottom. The halves are immediately reassembled after being taken off the rail, and a print is taken of the aperture on ordinary photographic paper. The print is fixed in hypo in the Office. The operation takes 8 minutes for moulding, and a period which varies, according to the light, from 5 minutes upwards for printing.

The instruments mentioned above all produce an exact profile of the rail, from which the weight in pounds per yard may be determined in the office by measuring the area in

square inches with a planimeter and multiplying by 10·2. The Stoker instrument, on the other hand, produces an outline which is ½ in. or ¾ in. outside the correct profile, and it is therefore necessary to use a transparent celluloid guide marked with circles of ½ in. and ¾ in. radii around a hole accommodating the tracing point of the planimeter.

This additional trouble is balanced by the ease of operation on the site, as the outline is marked directly on two pieces of card attached to a frame clamped round the rail, the marker being a pencil fixed at the centre of a wheel, of ½ in. or ¾ in. radius, which is run round the rail. Usually an outline is made with both sizes of marker, one outline checking the other. The relative position of the two cards is marked by pricking pairs of gauge points, one in each card and a fixed distance apart, both above and below the rail and by ruling a horizontal line across the top of the cards. The operation takes five minutes on the site, and the instrument can be removed hastily from the rail on the approach of a train without damaging the outline.

(3) Calipers and micrometer gauges may be used for finding the wear of rails by actual measurements, which may be compared with the nominal sections. The Grierson gauge is devised to permit direct computation of the weight if the wear is on the head. Side cutting cannot be measured effectively by calipers, although a sidecut profile can be plotted from dimensions taken with the Hepworth rule.

All the profiling devices require the services of (1) an Operator, (2) a Lengthman to clean the rails of rust and to clear a few inches of ballast from under the rail and (3) a look-out man. The positions at which records are taken should be methodically recorded and all profiles should be taken with the Operator facing the same way (*i.e.* facing traffic on a double line and facing the main line junction on a single line).

CHAPTER III.

PERMANENT WAY MATERIALS— SWITCHES AND CROSSINGS.

In order that a train may be diverted from one track to another, pairs or sets of switches or points, and crossings are necessary. All switch and crossing work, however complicated, is built up of three units termed :—

1. Switches ;
2. Common, or Ordinary, Acute Angle, or Vee Crossings ;
3. Obtuse Angle, or " K ", or Diamond Crossings,

together with the necessary intermediate closure rails. One pair of switches and one crossing with the closure rails are known as a ' turnout '. These units are described in the following pages.

1. SWITCHES.

There are three main types of switches used in this country today, known as :—

(*a*) *Straight switches.* These are an older type of switch, which have generally been superseded by semi-curved switches, though there are many switches of this type still in use.

(*b*) *Semi-curved switches.* These are the British Standard switches.

(*c*) *Curved switches.* These are a variation of the above in use on the Great Western Railway.

These are all illustrated in Fig. 20.

All sets of switches consist of four rails, two of which are known as stock or back rails, and two as switch or tongue rails. The switch rails are planed and the details of the planing vary with the type of switch. One stock rail and one switch rail fit together and are called a switch. The two outer rails of a pair of switches are the stock rails, and the two inner rails the switch rails. The switch rails are fixed together, by stretcher bars, and can be set to give a passage for traffic to either one track or the other. The switch rails pivot about a point known as the ' heel '.

(*a*) Straight Switches.

In this type the switch rail is straight from the tip or toe of the switches to the heel. The distance between the gauge faces of the switch rail and the stock rail at the heel, called the heel offset, or heel clearance, is generally $4\frac{1}{2}$", though in some cases it is $4\frac{1}{4}$". As will be seen from Fig. 20, the switch rail is planed from the tips to a point where the full thickness of the switch rail is obtained. These switches are made in various lengths, measured from the tip to the heel as given in Table No. 1 on p. 45. The switch angle* in units is found by dividing the length of the switch by the heel offset, which, as the switch rail is straight, is also equal to angle of divergence of the switch, which is the width of the rail head divided by the length of the planing. The longer the switch, the flatter is the angle of divergence.

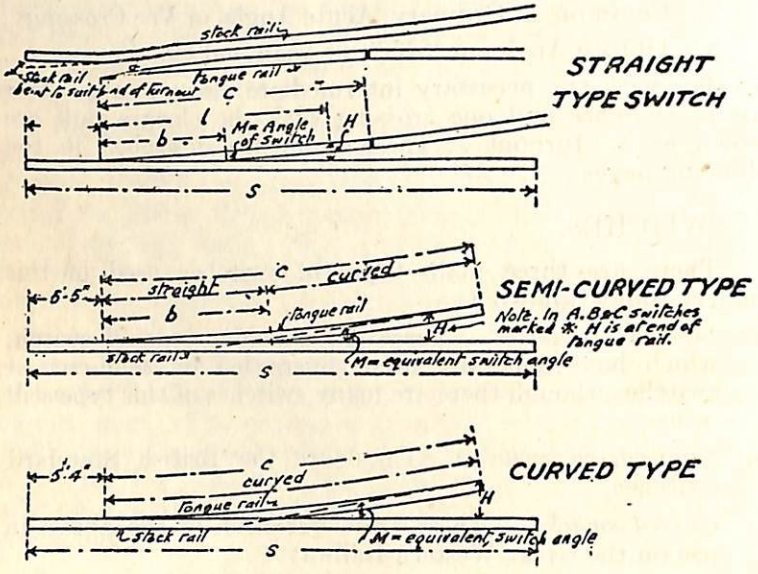


FIG. 20. SWITCHES.

The fittings of these switches are similar to those of the British Standard Switches given on p. 46.

(*b*) Semi-Curved Switches.

In this type the switch rail is straight from the tip to the end of the planing. From the end of the planing to the heel the switch rail is curved to a radius called 'the switch radius'. These switches are also made in various lengths, and the different lengths are known by the letters A to F, as given in

* For definition of unit angles *see* Page 62.

Table No. 1, below. The switch rail may be either ' undercut ' or ' straightcut '. In undercut switches, the switch rail at the tip is planed from a thickness of $\frac{3}{4}''$ at a depth of $1\frac{7}{8}''$ below the top to a fine edge at the top. In order to give more strength, the switch rail is cut to fit under the head of

TABLE 1.

DETAILS OF SWITCHES.

Switch No.	*Planing b*	*Tongue Rail C*	*Stock Rail. S*	*Tip of S.W. to heel. L*	*Clearance at heel. H*	*Switch angle. M*	*Radius of curved portion*	*Switch No.*
STRAIGHT TYPE SWITCH.								
9′	5′ 6″	11′ 6′	19′ 4″	9′ 0″	$4\frac{1}{2}''$	1 in 24	straight	9′
12′	7′ 4″	14′ 6″	30′ 0″	12′ 0″	$4\frac{1}{2}''$	1 in 32	,,	12′
15′	9′ 2″	17′ 6″	30′ 0″	15′ 0″	$4\frac{1}{2}''$	1 in 40	,,	15′
18′	11′ 0″	30′ 0″	45′ 0″	18′ 0″	$4\frac{1}{2}''$	1 in 48	,,	18′
24′	14′ 8″	29′ 7″	45′ 0″	24′ 0″	$4\frac{1}{2}''$	1 in 64	,,	24′
30′	18′ 4″	32′ 0″	44′ 4″	30′ 0″	$4\frac{1}{2}''$	1 in 80	,,	30′
SEMI-CURVED TYPE. R.E.A.								
+A	5′ 6″	20′ 0″	27′ 6″	18′ 11″	$11\frac{11}{16}''$	1 in 14·36	482′	A+
*A	5′ 6″	20′ 0″	27′ 6″	20′ 0″	$12\frac{5}{16}''$	1 in 13·96	482′	A*
+B	7′ 4″	22′ 6″	30′ 0″	21′ 5″	10″	1 in 18·43	613′	B+
*B	7′ 4″	22′ 6″	30′ 0″	22′ 6″	$10\frac{11}{16}''$	1 in 17·84	613′	B*
+C	9′ 2″	28′ 6″	36′ 0″	27′ 5″	$10\frac{5}{16}''$	1 in 22·68	960′	C+
*C	9′ 2″	28′ 6″	36′ 0″	28′ 6″	$10\frac{13}{16}''$	1 in 22·21	960′	C*
+D	11′ 0″	28′ 6″	36′ 0″	31′ 7″	$9\frac{33}{32}''$	1 in 27·94	1379′	D+
+E	14′ 8″	28′ 6″	36′ 0″	44′ 1″	$10\frac{3}{8}''$	1 in 36·17	2446′	E+
+F	20′ $7\frac{1}{2}''$	40′ 6″	43′ 10″	59′ 1″	$10\frac{1}{4}''$	1 in 46·92	3768′	F+
*F	18′ 4″	33′ 6″	41′ 0″	54′ 1″	$10\frac{5}{32}''$	1 in 45·68	3825′	F*
CURVED TYPE. G.W.R.								
B		22′ 6″	30′ 0″	22′ 6″	10″	1 in 19·01	730′	B
C		28′ 6″	36′ 0″	28′ 6″	$10\frac{1}{4}''$	1 in 23·53	1130′	C
D		30′ 0″	40′ 0″	30′ 0″	$8\frac{1}{4}''$	1 in 32·87	2000′	D

SWITCHES NOW USED ON BRITISH RAILWAYS.

Rly Group	*R.E.A. marked +*	*R.E.A. marked **	*Curved type*	*Straight type.*
G.W.R.			B.C.D.	30′
L.M.S.	D.E.	A.B.C.F.		
L.N.E.R.	D.E.	A.B.C.		
L.P.T.B.	D.E.	A.B.C.		
S.R.	A.B.C.D.E.F.			

the stock rail. In straightcut switches, the switch rail is planed from a thickness of $\frac{3}{4}''$ at a depth of approximately $2\frac{1}{2}''$ from the top to a virtual thickness of $\frac{3}{8}''$ at the top at a point $\frac{1}{2}''$ from the tip, and to a thickness of $\frac{1}{4}''$ at the tip. (These dimensions are slightly different in ' F ' type switches). In order to accommodate the thickness of the switch tongue at the tip in straightcut switches, the stock rail must be

joggled an amount equal to the thickness of the tongue, *i.e.* generally $\frac{3}{8}''$, as shewn in Fig. 21. This joggle is run out at a point 6″ in front of the tip, and at a point opposite to the end of the planing behind the tip. The gauge of the track in the switches is, therefore, wide over the length of the joggle up to a maximum of $\frac{3}{8}''$, and it is found that when traffic runs in a trailing direction through straightcut switches there is apt to be a shock just in front of the tip. For this reason, and also on account of their greater strength, straightcut switches are used in facing positions, and undercut switches are generally used in trailing positions. (A set of switches is called 'facing' when the greater part of the traffic over it runs from the tip towards the heel, and 'trailing' when the traffic generally runs from the heel towards the tip). Fig. 21 shews details of 'B' type Undercut and Straightcut switches.

The top of the switch rail is also planed at the tip to a certain depth below the top of the stock rail running out in a length equal to the side planing. In undercut switches this depth is $\frac{3}{32}''$ *i.e.* nearly $\frac{3}{4}''$, and in straightcut switches it is $\frac{1}{2}''$.

The fittings of these switches are as follows :—

(1). A number of switch slide chairs, known as 'P' chairs, and marked with the letter 'P', to which the stock rail is bolted, and which support the switch rail, allowing it to slide thereon, as shewn in Fig. 23. The amount the switch rail slides at the tip is generally $4\frac{1}{4}''$, but it is occasionally less than this when the switches are checked for use in a roadway.

The first 'P' chair is used at the tip of the switches, and the number of subsequent 'P' chairs depends on the type of the switch.

(2). A number of stud bolts, and cast iron distance blocks, which maintain the correct distance between the switch rails and stock rails, over that part of the length of the switch rail which slides. A stud bolt passes through the inside jaw of a 'P' chair and through the stock rail. A cast iron distance block is held against the web of the stock rail by a bolt which passes through the stock rail and the jaw of a 'P' chair. The web of the switch rail bears against the stud bolts and cast iron distance blocks when the switch rail is closed against the stock rail.

Cast iron distance blocks are made of different sizes to fit the different types of switch, and to suit the varying divergences of the switch rail from the stock rail. They are also handed to suit the right-hand or left-hand switch of a set of switches. (The right-hand switch of a set of switches is that on the right-hand when one is standing at the tip and facing the heel of the switches). The block nearest to the

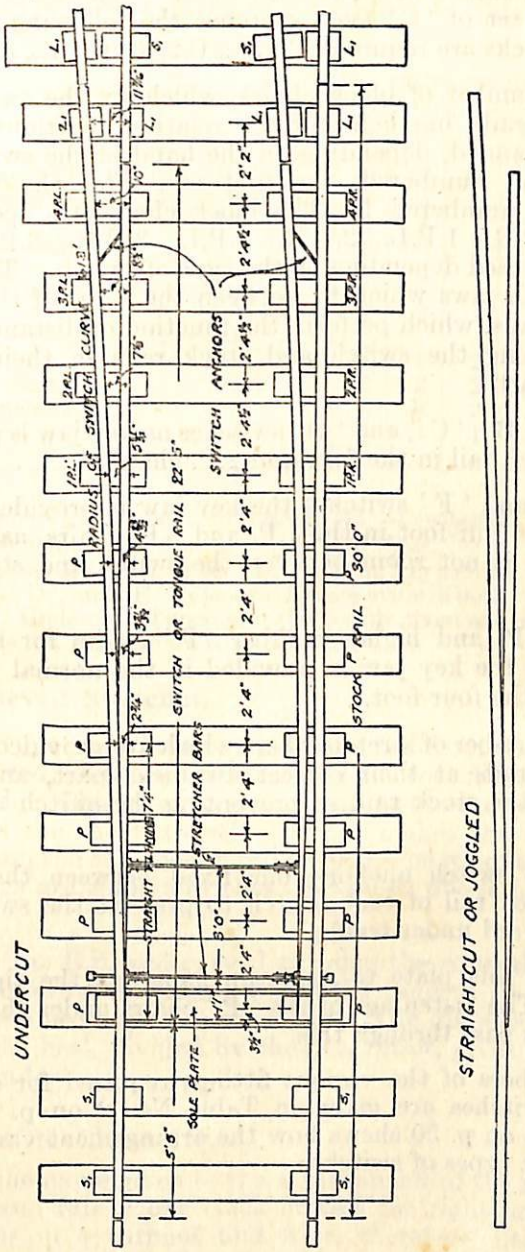


Fig. 21. 'B' Type Switches.

tip is numbered 1, and subsequent ones are numbered 2, 3. The third distance block is used in 'F' type switches only. Thus for a set of 'C' type switches the following cast iron distance blocks are required, C.1.R., C.2.R., C.1.L., and C.2.L.

(3). A number of block chairs, which fix the switch rails and stock rails in their correct relative positions. These chairs are handed, depending on the hand of the switch they support, and numbered, the first one after the last 'P' chair being numbered 1. The block chairs are accordingly marked 1.P.R., 1.P.L., 2.P.R., 2.P.L., 3.P.R., 3.P.L., etc., the number used depending on the type of switch. The chairs are cast with jaws which fit between the webs of the switch and stock rails, which perform the function of distance blocks in maintaining the switch and stock rails in their correct distance apart.

For 'A', 'B', 'C', and 'D' switches no key jaw is provided for the switch rail in the 1.P. and 2.P. chairs.

For 'E' and 'F' switches the key jaw is provided on the inside of the four-foot in the 1.P. and 2.P. chairs, as in these chairs there is not room between the switch and stock rails for the key.

In the 3.P. and higher number 'P' chairs for all types of switches, the key jaw is provided in the normal position, *i.e.* outside the four-foot.

(4). A number of stretcher bars which are provided to keep the switch rails at their correct distance apart, and which pass under the stock rail, so preventing the switch rail from rising.

(5). Two switch anchors, one fixed between the switch rail and stock rail of each switch to prevent the switch rail driving forward under traffic.

(6). One sole plate to maintain gauge at the tip of the switches. The fastenings of the 'P' chairs under the tips of the switches pass through this.

The numbers of the various fittings required for different types of switches are given in Table No. 2 on p. 49, and Table No. 3 on p. 50 shews how the arrangement varies with the different types of switches.

TABLE 2.

FITTINGS FOR SEMI-CURVED SWITCHES.

Fittings.	Type of Switches.					
	A	B	C	D	E	F
Slide Chairs (' P ' Chairs)	10	12	14	16	20	28
Block Chairs, right-handed (I.P.R. etc.)	4	4	5	6	9	11
,, ,, , left-handed (I.P.L. etc.)	4	4	5	6	9	11
Stock Rail Bolts	6	8	8	10	14	18
Stud Bolts	—	—	2	2	2	4
Cast Iron Distance Blocks, Right-handed	2	2	2	2	2	3
,, ,, ,, ,, , Left-handed	2	2	2	2	2	3
Stretcher Bars	2	2	2	3	3	4
Switch Anchors	2	2	2	2	2	2
Sole Plate	1	1	1	1	1	1

Notes :—

The Numbers given above are for one pair of switches.

All switch chairs have four fastenings per chair.

' F ' switches are made of the ' Straightcut ' Type only. ' A ', ' B ', ' C ', ' D ', and ' E ' Type switches are made in both ' Straightcut ' and ' Undercut ' Types, and the details given above, and in the Table on p. 50 apply to both types.

(*c*) **Curved Switches.**

In this type the whole of the switch rail from the tip to the heel is curved, and thus the planing is different from that of the B.S. switch. This gives an easier entrance to the switches and so reduces the shock to vehicles, but makes the switch rail thinner than the B.S. switch rail, over the length of the planing. The fittings are similar to those described above for the B.S. switch.

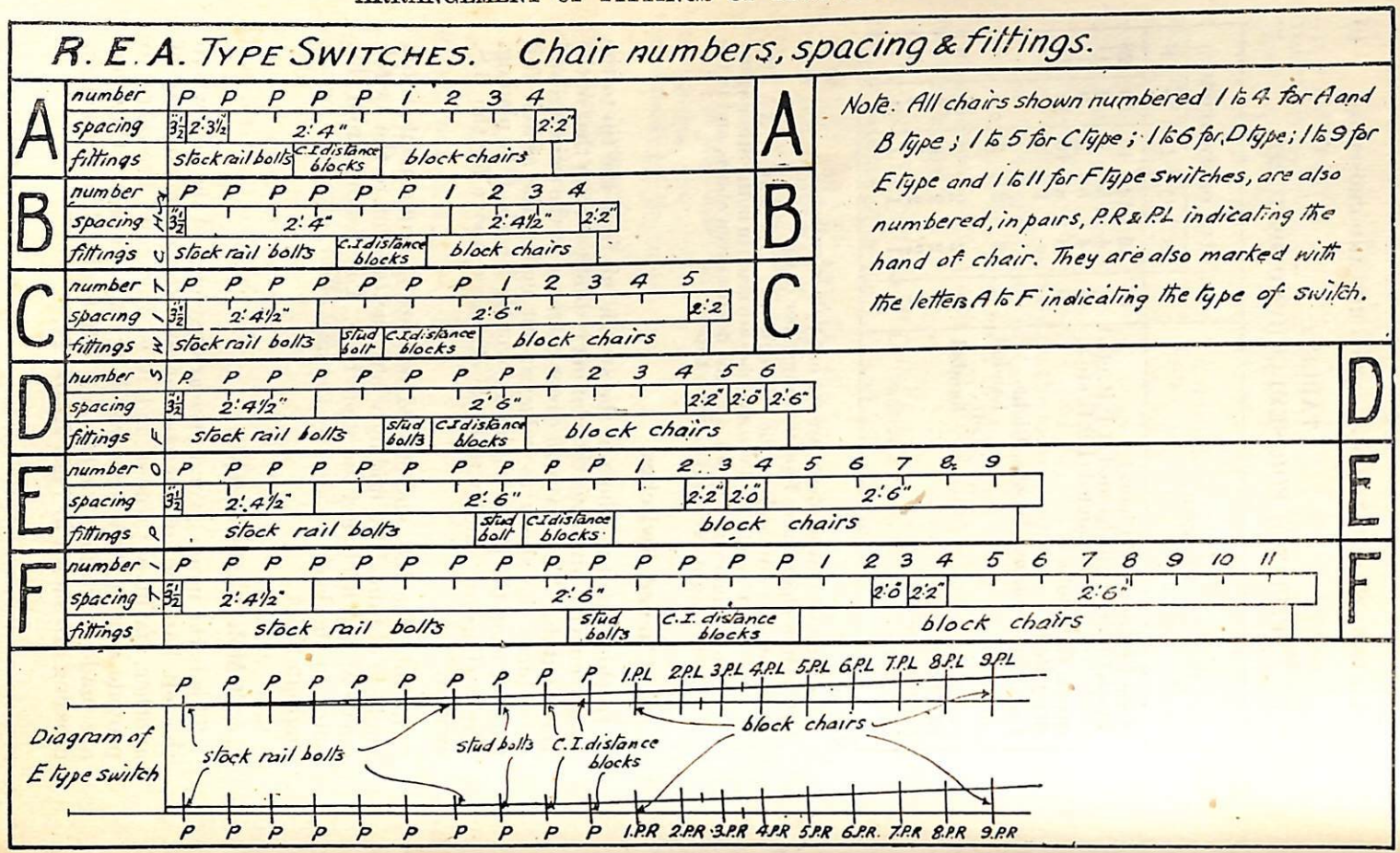
In both the B.S. and curved switches the equivalent switch angle is obtained by finding where the tangent to the switch curve at the heel cuts the stock rail. The distance from this point to the heel, divided by the heel offset, gives the switch angle in units.

2. COMMON CROSSING.

This is the name given to the arrangement of the rails where the left hand rail of one track crosses the right hand rail of another, as in a turnout and it is, therefore, necessary to provide a path for wheels travelling on both rails. Crossings are made of various angles, and details of a 1 in 8 common crossing are shewn in Figs. 22 and 24.

TABLE 3.

ARRANGEMENT OF FITTINGS OF SEMI-CURVED SWITCHES.


R. E. A. TYPE SWITCHES. Chair numbers, spacing & fittings.
A
number P P P P P 1 2 3 4
spacing 3½" 2'-3½" 2'-4" 2'-2"
fittings stock rail bolts C.I. distance blocks block chairs
B
number P P P P P P 1 2 3 4
spacing 3½" 2'-4" 2'-4½" 2'-2"
fittings stock rail bolts C.I. distance blocks block chairs
C
number P P P P P P P 1 2 3 4 5
spacing 3½" 2'-4½" 2'-6" 2'-2
fittings stock rail bolts stud bolt C.I. distance blocks block chairs
D
number P P P P P P P P 1 2 3 4 5 6
spacing 3½" 2'-4½" 2'-6" 2'-2" 2'-0" 2'-6"
fittings stock rail bolts stud bolts C.I. distance blocks block chairs
E
number P P P P P P P P P 1 2 3 4 5 6 7 8 9
spacing 3½" 2'-4½" 2'-6" 2'-2" 2'-0" 2'-6"
fittings stock rail bolts stud bolt C.I. distance blocks block chairs
F
number P P P P P P P P P P P P P 1 2 3 4 5 6 7 8 9 10 11
spacing 3½" 2'-4½" 2'-6" 2'-0" 2'-2" 2'-6"
fittings stock rail bolts stud bolts C.I. distance blocks block chairs
Note. All chairs shown numbered 1 to 4 for A and B type; 1 to 5 for C type; 1 to 6 for D type; 1 to 9 for E type and 1 to 11 for F type switches, are also numbered, in pairs, P.R. & P.L. indicating the hand of chair. They are also marked with the letters A to F indicating the type of switch.
Diagram of E type switch
P P P P P P P P P P 1.P.L 2.P.L 3.P.L 4.P.L 5.P.L 6.P.L 7.P.L 8.P.L 9.P.L
stock rail bolts
stud bolts
C.I. distance blocks
block chairs
P P P P P P P P P P 1.P.R 2.P.R 3.P.R 4.P.R 5.P.R 6.P.R. 7.P.R 8.P.R 9.P.R

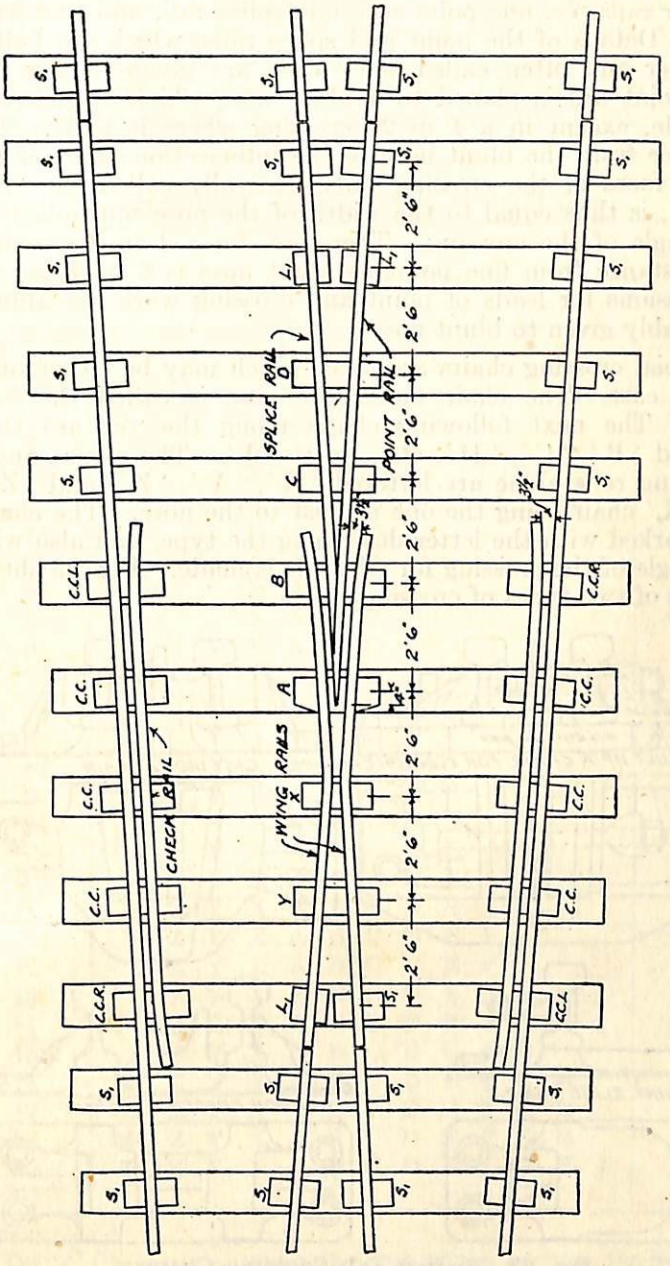


FIG. 22. 1 IN 8 COMMON CROSSING.

From Fig. 22 it will be seen that a common crossing consists of four rails, *i.e.* one point rail, one splice rail, and two wing rails. Details of the point and splice rails, which are bolted together and often called the 'Vee' are given in Fig. 24. The point rail is planed to a blunt nose which is generally $\frac{3}{4}''$ wide, except in a 1 in 20 crossing where it is $\frac{1}{2}''$. The distance from the blunt nose to the intersection point of the gauge faces of the crossing rails, generally called the 'fine point', is thus equal to the width of the nose multiplied by the angle of the crossing. Therefore, for a 1 in 8 crossing, the distance from fine point to blunt nose is $8 \times \frac{3}{4}'' = 6''$. Dimensions for leads of point and crossing work are almost invariably given to blunt nose.

Special crossing chairs are used, which may be either built up or cast. The chair under the nose is called the 'A' chair. The next following chairs along the vee are then lettered 'B', 'C', 'D', etc., up to 'J'. The chairs under the wing rails alone are lettered 'X', 'Y', 'Z', and 'Z¹', the 'X' chair being the one nearest to the nose. The chairs are marked with the letter describing the type, and also with the angle of the crossing for which it is made. Fig. 23 shews details of two types of crossing chairs.

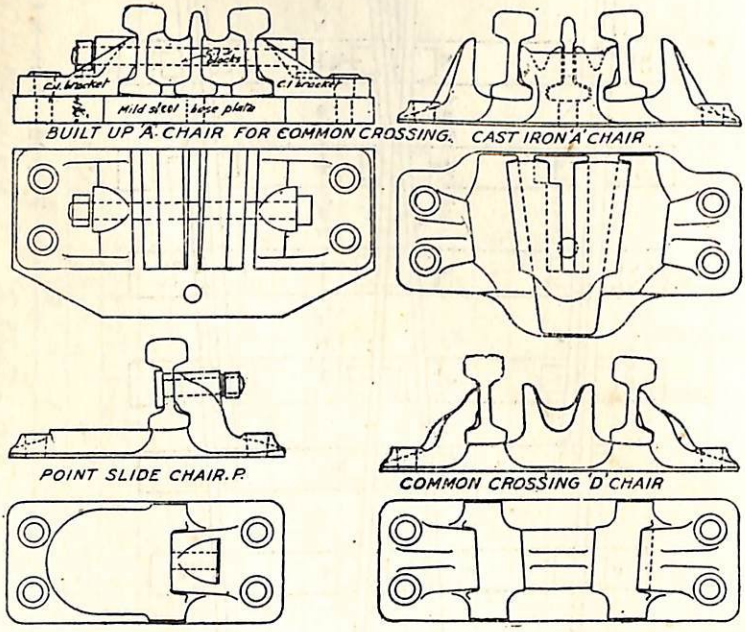


FIG. 23. SWITCH AND CROSSING CHAIRS.

The above chairs are not all needed for every crossing, as with sharp angled crossings, the rails diverge quickly, and

it is possible to use either bridge type chairs or standard chairs in place of the lettered chairs farther from the nose. Table No. 4 gives details of the special block chairs required for any angle, the letters opposite each angle of crossing, indicating which chairs are required. Thus for a 1 in 7 crossing the special chairs required are '7Y', '7X', '7A', '7B', '7C', and '7D'.

TABLE 4.
CHAIRING OF COMMON CROSSINGS.

Crossing 1 in	Chairs required	Crossing 1 in
1½	A	1½
2	A	2
2½	A B	2½
3	X A B	3
3½	X A B	3½
4	X A B	4
4½	X A B C	4½
5	X A B C	5
5½	X A B C	5½
6	X A B C	6
6½	Y X A B C	6½
7	Y X A B C D	7
7½	Y X A B C D	7½
8	Y X A B C D	8
8½	Y X A B C D	8½
9	Y X A B C D E	9
9½	Y X A B C D E	9½
10	Y X A B C D E	10
10½	Y X A B C D E	10½
11	Z Y X A B C D E	11
11½	Z Y X A B C D E F	11½
12	Z Y X A B C D E F	12
13	Z Y X A B C D E F G	13
14	Z Y X A B C D E F G	14
15	Z Y X A B C D E F G	15
16	Z[1] Z Y X A B C D E F G H	16
17	Z[1] Z Y X A B C D E F G H	17
18	Z[1] Z Y X A B C D E F G H	18
20	Z[1] Z Y X A B C D E F G H J	20

NOTES.—

The 'A' Chair comes under the nose of the crossing, the centre of the chair being 4″ from the blunt nose.

All crossing chairs are spaced at 2′ 6″ centres except the 'H' and 'J' chairs which are at 2′ 0″ centres.

With built up 'A' chairs a long bolt passes through the extended foot of the point rail shewn in Fig. 24, and through the base of the 'A' chair and the crossing timber. A washer plate is provided under the timber.

The correct distances between the rails are maintained by a number of cast iron blocks fitted between the webs of the rails in the flangeways. The blocks are held in position by $1\frac{1}{8}''$ diameter bolts which pass through them and the rails. The point and splice rails are bolted together by 1″ diameter bolts.

On most railways crossings are described as either 'right handed' or 'left handed', but on some railways, crossings are all of the same hand. To determine the hand of a crossing, one should stand at the blunt nose and look along the splice rail. If the splice rail is on the right hand side, the crossing is called right handed, and if it is on the left hand side, the crossing is called left handed, except on the Great Western Railway, where the side on which the point rail lies determines the hand of the crossing. The crossing shewn in Fig. 24 is thus left handed, except on the Great Western Railway, where it would be right handed. On railways where handed crossings are used, the point rail is placed in the track which carries the most important traffic. To determine which hand crossing is required for any turnout, stand at the switches and look towards the crossing. If the least important track is on the left, a left hand crossing is required, and if on the right a right hand crossing should be used, though, as mentioned above, on the Great Western Railway the reverse would be the case.

For siding connections in main lines, and little used crossover roads, the type of crossing shewn in Fig. 25, known as a 'spring crossing', is often used. The advantage of this type is that the gap which the main line traffic has to pass over in a fixed type crossing, is eliminated, as the wing rail in the least used track is normally held against the splice rail by the action of a spring. When traffic is passing over the least used track the wheels force the spring controlled wing over, and so make a flangeway for themselves. The wing returns to its normal position under the action of the spring after each wheel has passed. Experiments have been made with devices which retard the return of the wing and so allow a whole train to pass through before the wing returns to its position against the splice rail.

The check rails are relied upon to keep the wheels of traffic over the least used track from taking the wrong side of the nose, and it is therefore, essential in this type of crossing that the keys holding the check rail should be kept tight, and

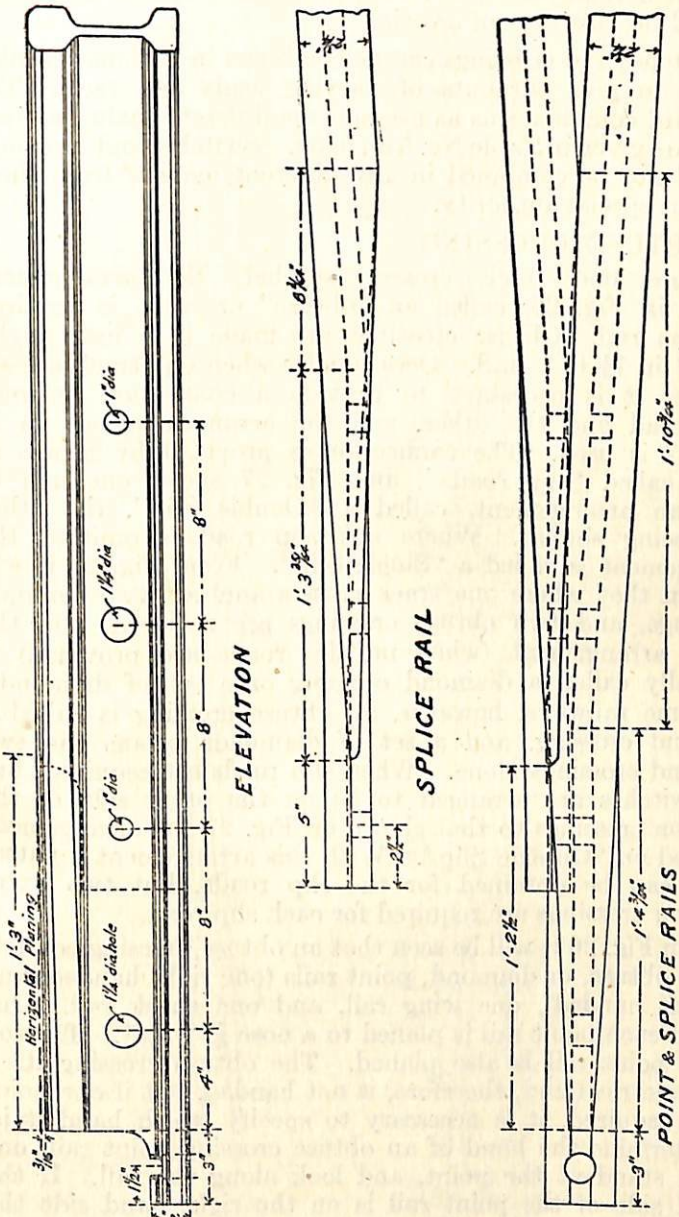


FIG. 24. DETAILS OF 1 IN 8 COMMON CROSSING.

the correct check rail flangeway maintained. Spring crossings are not normally used in facing positions. Special chairs are needed for this type of crossing.

Switches and crossings can be combined in various arrangements to give turnouts of varying leads and radii. The standard combinations as used on the different main line railways are given in Table No. 5 on p. 58. Switches and crossings should not be combined in any different manner from these without special authority.

3. OBTUSE CROSSING.

Where one track crosses another, the arrangement shewn in Fig. 26, called an 'obtuse' crossing, is required on each rail. Obtuse crossings are made in $\frac{1}{2}$ unit angles from 1 in $1\frac{1}{2}$ to 1 in 8. Occasionally when one track crosses another it is necessary to provide a connection between each road and the other, and the arrangement shewn in Fig. 27 is used. The connection is provided by means of roads called 'slip roads', and Fig. 27 shews one half of such an arrangement, called a 'Double Slip', the other half being similar. Where one slip road is omitted the arrangement is called a 'Single Slip'. From Fig. 27 it will be seen that where one track crosses another, two common crossings, and two obtuse crossings are required, and the whole arrangement (when no slip roads are provided) is generally called a diamond crossing or a set of diamonds. On some railways, however, an obtuse crossing is called a diamond crossing, and a set of diamonds means the two diamond crossings alone. When slip roads are required, but the switches are arranged to be on the other side of the common crossings to that shewn on Fig. 27 the arrangement is called on 'Outside Slip'. With this arrangement a flatter curve can be obtained for the slip roads, but two extra common crossings are required for each slip road.

From Fig. 26 it will be seen that an obtuse Crossing consists of two obtuse, or diamond, point rails (one right handed, and one left handed), one wing rail, and one check rail. One edge of each point rail is planed to a nose $\frac{3}{4}''$ wide*. The top of the point rail is also planed. The obtuse crossing itself is symmetrical and, therefore, is not handed, but if one point rail is required, it is necessary to specify which hand it is. To determine the hand of an obtuse crossing point rail, one should stand at the point, and look along the rail. If the planed side of the point rail is on the right hand side the point rail is right handed, and if on your left hand side, the point rail is left handed.

* It is the practice on some Railways to plane the point rails of $6\frac{1}{2}$, 7, $7\frac{1}{2}$ and 8 obtuse crossings to a nose of $\frac{1}{2}''$.

FIG. 25. 1 IN 8 SPRING CROSSING.

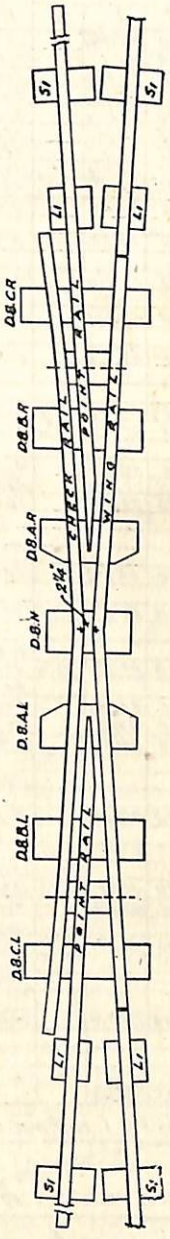
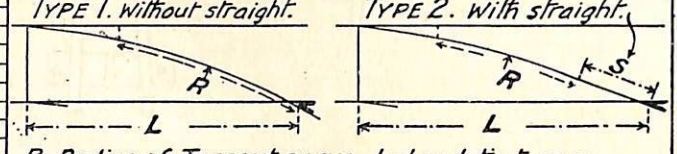


FIG. 26. 1 IN 8 OBTUSE CROSSING.

TABLE 5.
STANDARD LEADS OF MAIN LINE RAILWAYS.

SWITCH.	CROSSING	G.W.R.			L.M.S.			L.N.E.R.			L.P.T.B.			S.R.		
		R	L	S	R	L	S	R	L	S	R	L	S	R	L	S
A	4				130'	42·10 3/32		130'	42·10 3/4		130'	42·10 1/4				
	4½				168	45·1		168	45·1		168	45·1				
	5				212	47·1 3/32		212	47·1 1/4		212	47·1 1/4		212'	46·11 1/2	
	5½				264	49·1 3/32		264	49·1 1/2		264	49·1 1/2		264	49·0	
	6				326	50·11 1/16		310	50·7	1'0 1/2	326	50·11 1/4		325	50·11 1/4	
	6½				398	52·9 1/8		398	52·9 1/4		398	52·9 1/4		396	52·9 1/2	
	7				482	54·5		482	54·5		482	54·5		482	54·5	
	7½				482	54·7 1/8	4·9 1/16	482	54·8 1/4	5·3 1/4	482	54·7 3/4	4·9 1/4			
	8				482	55·1 3/32	9·2 1/16	482	55·1 1/2	9·8 1/4	482	55·1 1/2	9·2 3/4			
B	6	310'	58·1"		312	57·1 1/32		312	57·1		312	57·1				
	6½	340	59·2 1/4													
	6⅔	371	60·3 1/4		374	59·2 3/8		374	59·2 1/2		374	59·2 1/2				
	6¾	405	61·4 1/4													
	7	439	62·5 3/8		445	61·3 3/32		422	60·7 1/4	1·5	445	61·3		445	61·1 1/2	
	7⅓	478	63·5 3/8													
	7½	516	64·6 1/4		524	63·2 3/32		524	63·2 3/4		524	63·2 3/4		524	63·1 3/4	
	7⅔	560	65·6 1/4													
	8	603	66·6		613	65·1 1/8		613	65·1 1/2		613	65·1 1/2		612	65·1 1/4	
	8⅓	652	67·5 1/2													
	8½	702	68·5													
	9				613	65·8 11/16	9·1 1/4	613	65·8 1/4	9·8	613	65·8 1/4	9·1 1/4			
	10				613	67·1 3/32	17·3 3/32	613	67·1 1/4	17·10 1/2	613	67·1 3/4	17·3 1/4			
	11										613	69·2 1/4	24·10 1/4			
C	7				416	69·3 1/16		416	69·3 1/4		415	69·5 1/2				
	7⅓				485	71·6 1/32		485	71·6		485	71·7 1/4				
	8	558	74·11 1/4		562	73·7 1/2		562	73·7 1/2		561	73·9 1/2		563	73·5 1/2	
	8⅓	598	76·0 1/8													
	8½	641	77·1											647	75·6 3/4	
	8⅔	686	78·1 1/2													
	9	732	79·2		740	77·7 9/16		740	77·8		740	77·8		740	77·7 1/4	
	9½	832	81·2 1/8											842	79·6 3/4	
	10	942	83·1 5/8		960	81·5		955	81·6 1/4		960	81·5		960	81·5	
	10½	1062	85·0 1/2													
	11							918	81·6 1/4	10·5 1/2	960	81·11 1/2	9·6 11/16			
	12				960	83·2 11/32	17·5 3/16	960	83·2 1/8	18·2 1/2	960	83·2 1/2	17·5 3/4			
	14							960	85·4 3/4	32·8	960	87·1 1/4	32·8 1/4			
D	8				545	80·6 3/16		545	80·6 1/4		545	80·6 1/4				
	9				707	85·2		707	85·2		707	85·2				
	10	868	93·6 1/8		896	89·6 3/32		876	89·1 3/4	10 1/2	896	89·6 3/4		893	89·8 1/2	
	10½	969	95·8 1/2											999	91·10	
	11	1077	97·10 1/4					1120	93·9		1118	93·9		1114	93·11	
	11½	1194	99·11 3/4											1239	95·11 1/4	
	12	1320	102·0		1379	97·8 1/4		1219	96·6 1/8	11 1/4	1379	97·8 1/2		1379	97·8 1/2	
	12½	1455	103·11 1/8													
	13	1600	105·11 1/2													
	14							1379	99·2 1/2	17·8 1/4	1379	99·2 1/2	17·8 1/4			
	16				1379	102·9 3/16	33·5 1/16	1379	102·9 1/4	34·5 1/2	1379	102·9 1/4	33·5 1/16			
E	10				834	104·10 1/2		806	104·1 3/4	1·3 1/4	834	104·10 1/2				
	11							1027	109·6 1/2		1027	109·6 1/2				
	12				1246	114·0 1/8		1121	111·8 1/2	4·7 1/4	1246	114·0 1/2		1243	114·1 3/4	
	13													1491	118·5 1/2	
	14							1774	122·5 1/4		1774	122·5 3/4		1771	122·7 1/4	
	15													2087	126·7	
	16				2446	130·3 1/8		2446	130·3 1/2		2446	130·3 1/2		2449	130·3 3/4	
F	16													2253	151·3 1/4	
	17													2591	155·5 1/4	
	18													2963	159·6 3/4	
	20				3825	162·5 11/16								3770	168·5 1/2	
30'	13	1504'	127·6"													
	13½	1626	130·10 1/2													
	14	1752	134·0 1/4													
	14½	1884	137·2 1/8													
	15	2021	140·4													
	15½	2163	143·5													
	16	2311	146·5 1/8													
	16½	2464	149·6													
	17	2623	152·5 1/4													
	17½	2788	155·5 3/8													
	18	2958	158·4 1/2													
	18½	3134	161·3 3/4													
	19	3316	164·1 1/4													
	19½	3504	166·11 1/8													
	20	3698	169·9 3/4													



R = Radius of Turnout curve. L = Lead tip to nose
S = Length of straight

The chairs under the noses of the point rails are called 'A' chairs, and the next following along the point rail 'B' and 'C' chairs. For obtuse crossings of 1 in $1\frac{1}{2}$ to 1 in $3\frac{1}{2}$ angles inclusive 'A' chairs only are required. From 1 in 4 to 1 in 7 inclusive 'A' and 'B' chairs are needed. For 1 in $7\frac{1}{2}$ and 1 in 8 obtuse crossings 'A', 'B' and 'C' chairs are used. These chairs are also either right handed or left handed.

The 'A' chairs may be either built up or cast, the 'B' and 'C' chairs are generally cast. When built up 'A' chairs are used, the point rail has an extended foot at the hole, and a long holding down bolt passes through this, through the base of the 'A' chair and the crossing timber, but this is not required with solid cast iron 'A' chairs. At the narrowest point between the wing and check rails, *i.e.* the centre of the crossing, which is known as the knuckle or knee, a chair known as the 'N' chair is used in 1 in $5\frac{1}{2}$ to 1 in 8 obtuse crossings. This chair is symmetrical and is not handed. Every special chair for a obtuse crossing has marked on it, the letter 'D', standing for diamond, the angle of the crossing, and the type of chair, *i.e.* either 'N', 'A', 'B', or 'C'. The 'A', 'B', and 'C' chairs also have either 'R' or 'L' marked on depending on whether the chair is right or left handed. Thus the chairs required for a 1 in 8 obtuse crossing are one of each of the following types:— 'D8CL', 'D8BL', 'D8AL', 'D8N', 'D8AR', 'D8BR', and 'D8CR' chairs.

The distance between the centre of the knuckle and the nose of the point rail, can be obtained approximately by multiplying the sum of the width of the nose plus the flangeway clearance by the angle of the crossing. Generally the width of the nose is $\frac{3}{4}''$ and the flangeway clearance is $1\frac{3}{4}''$, and their sum is thus $\frac{3}{4}'' + 1\frac{3}{4}'' = 2\frac{1}{2}''$. The expression to find the distance from nose to knuckle for any crossing 1 in N is thus $N \times 2\frac{1}{2}''$. The distance between the noses of the two point rails is twice this amount. Thus for a 1 in 8 diamond, the distance between the noses by this rule is twice $8 \times 2\frac{1}{2}'' = 2 \times 8 \times 2\frac{1}{2}'' = 40''$ The standard distance is $3'\ 4\frac{1}{16}''$, so that the rule is fairly accurate.

Owing to the large gap that would be obtained with flat angles, the type of diamond crossing previously described is not used for angles flatter than 1 in 8. Instead the arrangement shewn in Fig. 28, called 'Switch Diamonds' is used.

As will be seen from the figure, the arrangement is virtually two sets of switches with 4" between the tips of the switch blades. The Switch Diamonds can be set to give a passage for a vehicle on either road, and a continuous support is provided for the wheels through the crossing.

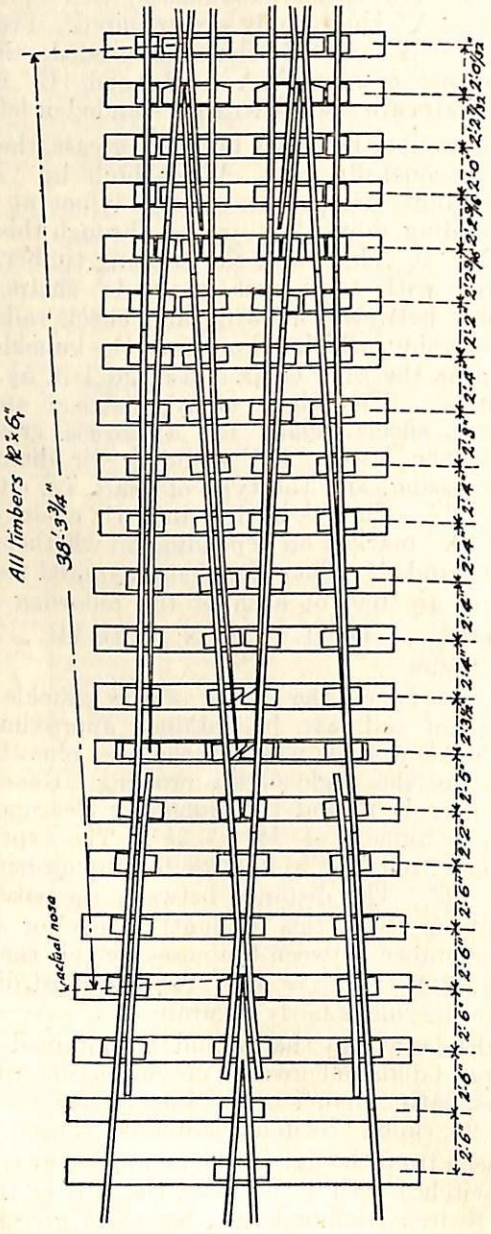
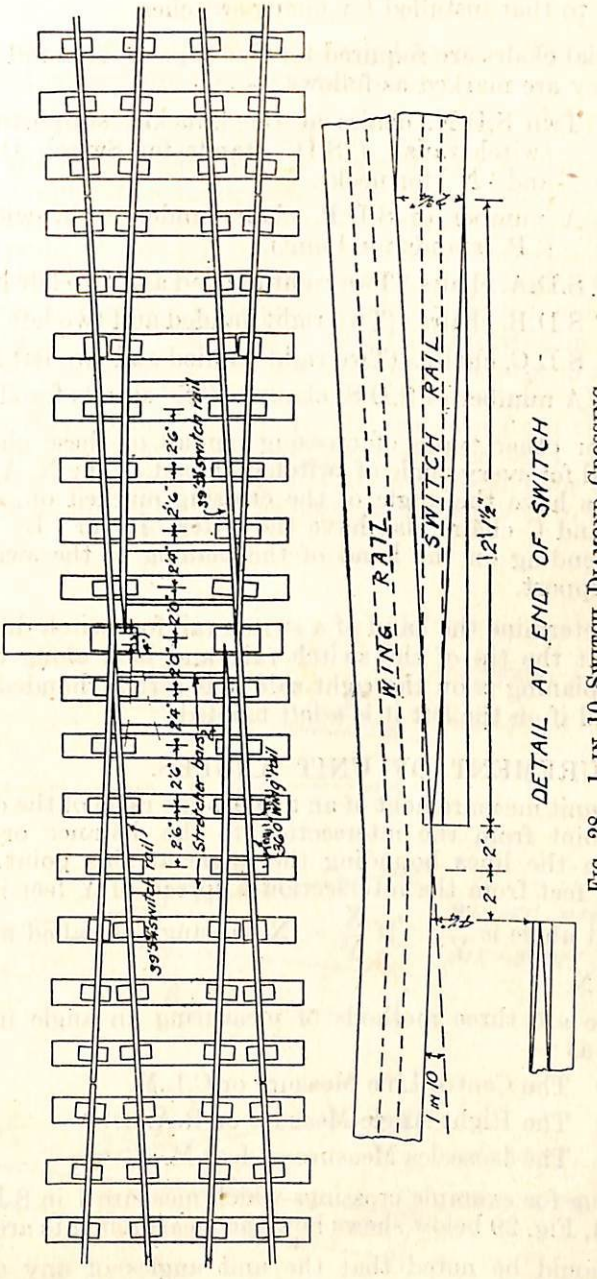


FIG. 27. 1 IN 8 DOUBLE SLIP.


39'-3" switch rail
6 @ 2'-6" = 15'-0"
Stretcher bars
39'-3" switch rail
6 @ 2'-6" = 15'-0"
(320 Alloy rail)
WING RAIL
SWITCH RAIL
1 IN 10
2'
2'
2'

Switch Diamonds are controlled from a Signal Box, and the detection and locking of them with the junction signals is similar to that installed for facing switches.

Special chairs are required for this type of diamond crossing and they are marked as follows :—

(1). Two S.D.N. chairs at the knuckle, supporting both switch rails. (' S.D.' stands for Switch Diamond, and ' N ' for neck).

(2). A number of S.D.P. chairs under each switch rail. (' P ' stands for Point).

(3). S.D.A. chairs (Two right handed and two left handed).

(4). S.D.B. chairs. (Two right handed and two left handed)

(5). S.D.C. chairs. (Two right handed and two left handed)

(6). A number of S.D.S. chairs. (' S ' stands for slide).

As for other types of crossing not all of these chairs are required for every angle of switch diamond. The N, A, B, and C chairs have the angle of the crossing marked on, and the A, B, and C chairs also have the letter ' R ' or ' L ' marked on depending on the hand of the planing of the switch rail they support.

To determine the hand of a switch rail for switch diamonds, stand at the tip of the switch rail, and look along the rail. If the planing is on the right side it is a right handed switch rail, and if on the left it is a left handed.

MEASUREMENT OF UNIT ANGLES.

The unit measurement of an angle is the ratio of the distance of a point from the intersection to the distance or spread between the lines bounding the angle at this point. Thus if at X feet from the intersection a spread of Y feet is found the unit angle is $\frac{X}{Y}$. If $\frac{X}{Y} = N$ the angle is called an angle of 1 in N.

There are three methods of measuring an angle in units, known as :—

(*a*) The Centre Line Measure or C.L.M.

(*b*) The Right Angle Measure or R.A.M.

(*c*) The Isosceles Measure or Isos.M.

Taking for example crossings which measure 1 in 8 by each method, Fig. 29 below shews how the measurements are taken.

It should be noted that the unit angles of any crossing measured by the three methods are not the same.

Thus a crossing of which the unit angle by C.L.M. is 1 in 8 is a unit angle of 1 in 7·969 by R.A.M. and 1 in 8·016 by Isos.M.

The Centre Line Measure is adopted by most British Railways, and is used throughout this book.

The usual method of applying this to an angle is as follows :

Find the point where there is a spread of 1 ft. between the lines bounding the angle, measured at right angles to the centre line of the angle. Then the distance in feet from the middle point of this 1 ft. dimension to the intersection is the unit angle by C.L.M. It is important when applying the unit angle to calculations to remember that it is a number, and not a dimension. When measuring the intersection of long tangents, it is generally more accurate to use a larger dimension than 1 ft. between the lines bounding the angle. The unit angle is then found by dividing the distance from the intersection to the centre of whatever spread is used, *i.e.* if in measuring an angle a spread of 4′ 0″ is used, and the distance from the middle of this to the intersection is found to be 36′ 0″ the unit angle is $\frac{36' 0''}{4' 0''} = 9$.

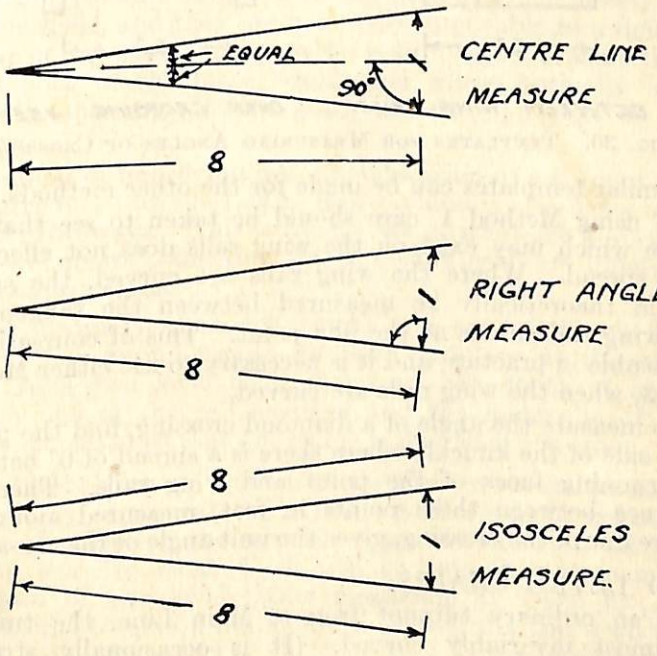


FIG. 29. MEASUREMENT OF UNIT ANGLES.

There are a number of methods of applying this to a common crossing, and the most usual are given below :—

(1). Find the point where there is a spread of 6″ between the running or gauge faces of the wing rails, and the point where there is a spread of 6″ between the running faces of the point and splice rails. Then the distance between these points in feet measured along the centre line of the crossing, is the unit angle of the crossing.

(2). Find the point where there is a spread of 6″ plus the width of the blunt nose between the running edges of the point and splice rails, *i.e.* generally 6″ + $\frac{3}{4}$″ = 6$\frac{3}{4}$″. Then twice the distance in feet from this point to the blunt nose gives the unit angle of the crossing.

(3). Find the two points where there are spreads of 1″ and 7″ respectively between the running faces of the point and splice rails. Then twice the distance between these points in feet gives the unit angle of the crossing.

It is useful to have metal templates made to give the spread required, and Fig. 30 gives details of suitable ones for Method 1.

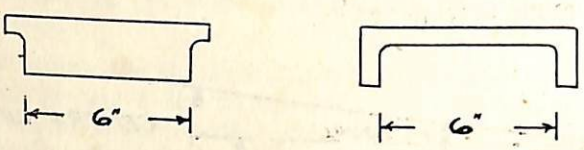


FIG. 30. TEMPLATES FOR MEASURING ANGLES OF CROSSINGS.

Similar templates can be made for the other methods.

In using Method 1, care should be taken to see that any curve which may exist on the wing rails does not effect the true spread. Where the wing rails are curved, the spread should theoretically be measured between the tangents to the wing rail curves at the fine point. This of course is not applicable in practice, and it is necessary to use either Method 2 or 3, when the wing rails are curved.

To measure the angle of a diamond crossing, find the points each side of the knuckle where there is a spread of 6″ between the running faces of the point and wing rails. Then the distance between these points in feet, measured along the centre line of the crossing, gives the unit angle of the crossing.

TWO LEVEL CHAIRS.

In an ordinary turnout from a Main Line, the turnout is almost invariably curved. (It is occasionally straight when it is on the outside of a curved main). The turnout

curve should, therefore, have superelevation, but owing to the long timbers which are necessary to pass under both roads, it is not possible to provide this, and for this reason, among others, it is necessary to impose a speed restriction on traffic passing over a turnout. Where the main is curved and superelevated and the turnout is on the outside of the main, and curved in the opposite direction a worse condition exists as the turnout will have superelevation on the wrong rail, *i.e.*, the inside rail will be higher than the outside.

This lack of superelevation, or superelevation on the wrong rail of a turnout, besides causing discomfort to the passengers travelling over it greatly increases the strain on the fastenings of the track.

In the past efforts have been made to improve these conditions by such means as adzing the chair seatings on the inside rail of the turnout, and/or placing chair packings under the other chairs. Neither of these methods is entirely satisfactory as adzing of chair seatings cuts away the part of the timber that has been creosoted, makes a pocket for water, and weakens the timber, and chair packings tend to split, and they both decrease the length of chair fastenings in the timber.

It is not possible to get over the difficulty completely by these methods, and they are not easily applicable to a double line junction, where the outside road of the branch lines crosses both of the main roads, and where normally long timbers supporting all four roads are used for part of the junction.

A method of improving the superelevation of a turnout has been introduced by the L.M.S. Railway and is also being used on other Railways. This is by the use of what are known as ' two level chairs ', and they are especially useful in junctions and crossover roads.

In an ordinary chair for switch and crossing work that supports two running rails, the two rails are at the same level. In a two level chair, however, the depth of metal between one of the rail seatings and the underside of the chair is increased so that one rail is higher than the other.

Two level chairs are made with the chair seatings increasing in depth by increments of a fraction of an inch, generally $\frac{1}{12}''$ or $\frac{1}{16}''$. Taking the average chair spacing in point and crossing work to be 2′ 6″, it will be seen that by using a succession of two level chairs increasing in depth by $\frac{1}{12}''$, it is possible to obtain a difference of level of 1″ between two rails in a distance of $12 \times 2' 6'' = 30'$. If the chair seating depth increases by $\frac{1}{16}''$ the distance necessary to obtain

a difference in level of 1″ is 16 × 2′ 6″ = 40′.* Thus with two level chairs on the outside rail of a turnout, and normal chairs on the inside it is possible to obtain a superelevation for the turnout road of 1″ in a distance of about 30′ or 40′.

In a switch the switch and stock rail have to be at the same level from the tip to the end of the straight planing.

From this point onwards two level chairs can be used, and the level of the outside switch rail of the turnout raised above the adjacent stock rail. In order to make the switch rail seat properly on the higher level slide chairs, it is necessary to give a vertical set in the switch rail equal to the gain in height at its heel over the length from the end of the straight planing to the heel.

By giving a rake to the long timbers it is possible to use lower two level chairs than would otherwise be necessary. The timbers are raked by an amount equal to half the superelevation required for the turnout in the gauge, as explained below.

Assume that at the crossing of a turnout in a straight main 2″ superelevation is required on the turnout, the long timbers are then raked to give a 1″ fall across the gauge. (This means that, if normal chairs were used, there would be a superelevation of 1″ on the main and the turnout). Standard chairs are then used for the main line rail opposite to the crossing. As the two main line rails are to be level, and also the point and splice rails have to be level at the crossing, chairs having a base for both rails thicker than standard by an amount equal to the rake, in this case 1″, are used here.

Standard chairs are then used on the turnout rail opposite the crossing. The superelevation on the turnout is then equal to the sum of the increased thickness of the base of the crossing chairs, *i.e.* 1″ in this case, and the rake of the timbers again 1″, and thus the required superelevation of 2″ is obtained.

It is not possible to use two level chairs in a diamond crossing, as the two main line rails and the two branch line rails at a set of diamonds obviously have to be the same level for a straight main line, or have the same superelevation as the main in a curved main line.

At a junction in a straight main, where it is desired to superelevate the branch line, it is, therefore, necessary to re-design the junction so that the branch line is straight through diamonds.

In order to do this, and, at the same time provide a good curvature through the remainder of the junction, it is generally

* Usually termed a superelevation gradient of 1″ in 40′, or 1 in 480.

necessary to widen the six-foot of the main appreciably, which makes the work expensive.

There are cases, however, where the raising of the speed restriction on the branch line at a junction, which is possible when the branch is superelevated, gives such increased facilities to the Traffic Department that the cost is justified.

In many junctions, however, there is not room for the widening of the six-foot that two level chairs necessitate, and in these cases their use is not practicable. Their use is, however, generally applicable to turnouts, such as connections to and from loop lines, and also to crossover roads.

It is essential that point and crossing work with two level chairs should receive very careful maintenance. For instance a joint which is $\frac{1}{4}''$ low in a standard turnout may not be very serious, though of course it should have attention, but in two level point and crossing work, with a superelevation gradient of between 1″ in 30′ and 1″ an 40′, a $\frac{1}{4}''$ low joint will considerably affect the running of traffic over it, and may increase the superelevation gradient to as much as 1″ in 20′. This applies especially where long timbers are raked, and these must be firmly packed under each rail, and the correct rake maintained.

Fig. 31 shews a thick base chair compared with a standard L.M.S. 'A.S.I.' chair. The letter T and figure 12 on the thick base chair indicate that the base is $1\frac{2}{3}''$, *i.e.* 1″ thicker than the standard chair. Fig. 32, of two of the heel chairs of 'D' type switches, shews how the switch rail is raised above the stock rail.

TIMBERING OF SWITCH AND CROSSING WORK.

The timber spacing to be used for standard switch and crossing connections is generally laid down by each Company, but a number of cases occur in practice where standard spacing cannot be used, and it often calls for great ingenuity to space satisfactorily the timbers of a complicated layout. The following points should be borne in mind when this work has to be done :—

(1) Chairs which support two or more rails which are at an angle to each other will only fit the rails at one point, and they must be put on in their coreect position otherwise the alignment of the rails they support will be spoilt, and the rails will not sit properly in their seatings.

(2) Chairs on opposite rails of one track should be square to each other. Where one timber is required to pass under two roads which meet at an angle, it is not possible to

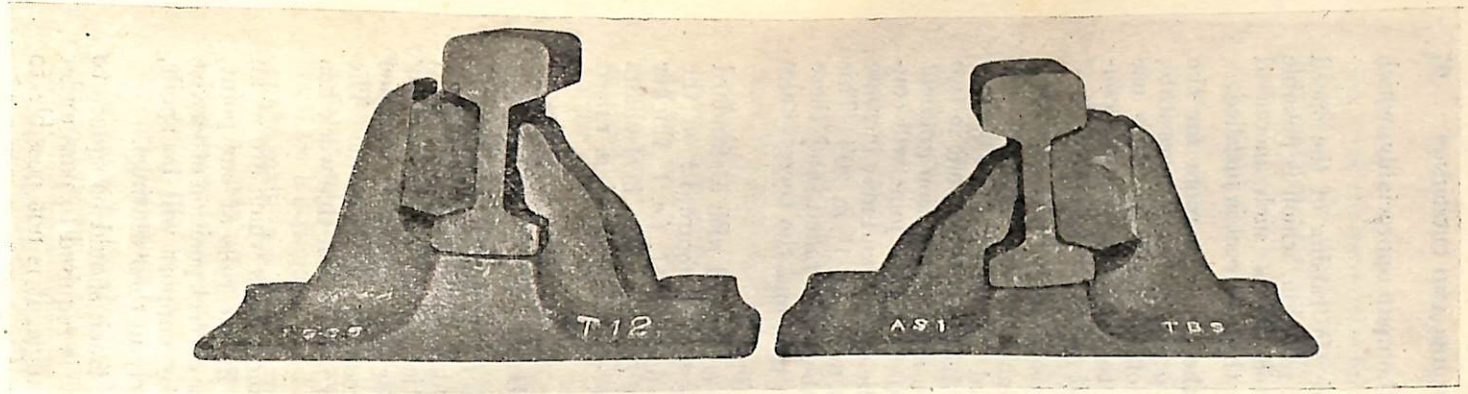


Fig. 31.

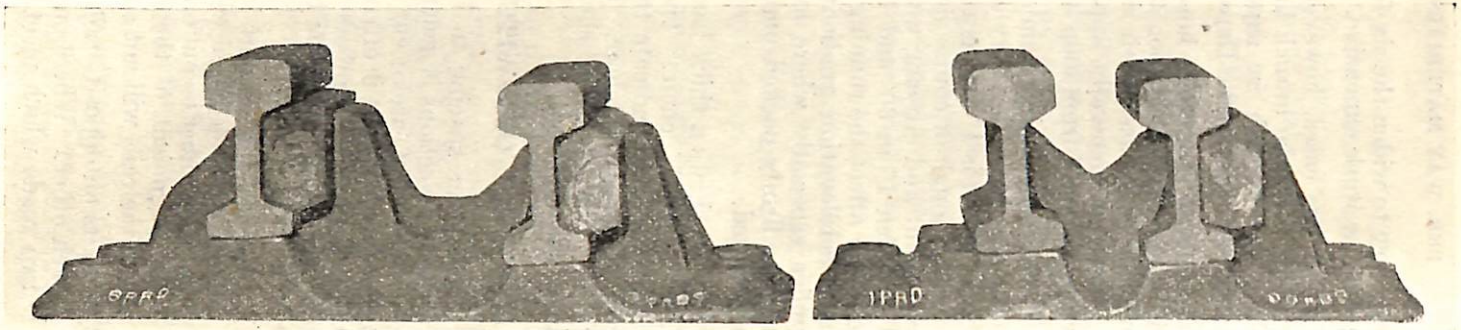


Fig. 32.

place the timber square to both roads, and it is, therefore, generally placed square to the centre line of the angle at which the two roads intersect. Then in order to place the chairs on each road square to each other it may be necessary to have a timber wider than normal, otherwise the chair fastenings will come off the timber or too close to the edge to give a good hold.

(3) It is better to avoid as much as possible the ' interlacing ' of timbers, *i.e.* setting the timbers of one road in the spaces between the timbers of a converging road, as under these conditions it is very difficult to pack the timbers satisfactorily. As many timbers as possible should be used supporting all the rails of adjacent point and crossing work. Where the timbers required would be too long to be handled comfortably, two short timbers may be ' halved ' together to form one long one. This consists of cutting out the top half depth of the end of one timber for about 12″ in length, and the bottom half of the abutting one for the same length, and placing these two cut portions together one on top of the other. They should be bolted or screwed together.

(4) Occasionally at switches a longer timber is required to take signalling apparatus, such as the motors for power operated points, and for extended sole plates. Such an arrangement is shewn in Fig. 28 of a set of switch diamonds.

(5) In switch and crossing work it is often necessary to provide a clear space for signal wires and point rods. In complicated layouts this may mean that the ideal arrangement of timbers is not obtainable, but the signalling apparatus should be so arranged as to interfere as little as possible with timber spacing.

CATCH ROADS.

Where a siding joins a running line, the Ministry of Transport requires that a catch or trap road must be provided to ensure that any vehicle on the siding running away or over-running the siding signal is diverted from the main line. If the catch road were not provided there would be a risk of a collision between traffic on the running line and the vehicle on the siding, or the latter might damage the switches of the siding turnout if these were not set for traffic leaving the siding.

Catch Roads may be arranged so that a vehicle traversing them is derailed, or they may be provided with stops. In either case they should be so positioned that at no point does

a vehicle when on them, or when derailed, come nearer than 6′ 0″ to the main line, after allowing for any superelevation and overthrow on the main, when the latter is curved.

The following are the usual types of Catch Roads :—

(1) Single Catch Tongue—This consists of a single switch usually placed in the siding rail further from the main line.

(2) Catch Points.—These consist of a pair of switches, and it is usual to make the rail nearer to the main longer than the other.

(3) Catch Points with Crossing.—In this type the rail nearer the main is continued and a crossing inserted in the siding. A short lead is generally used for this type.

(4) Catch Road with stops.—These form a dead end siding, which should be long enough to accommodate a vehicle clear of the fouling point between the catch road and the siding. Occasionally buffer stops are used at the end of such catch roads, or the ends of the rails may be turned up, but the most satisfactory arrangement is to have a mound of sand or similar material at the end of the catch road, as with this there is hardly any shock to a vehicle running away into the catch road.

A development of this is known as a 'sand drag'. In this, boards are fixed to the sleepers clear of the chairs, by brackets, one each side of each rail, so that they are parallel to the rails, and project an inch or two above rail level, like the sides of a box round each rail. The space between each pair of boards is filled with sand, beach or similar material, so that the rails are just covered. A vehicle running over this is quickly brought to rest, especially if the sand drag is arranged to be on a rising gradient. The length of a sand-drag is determined by local conditions, a usual length being 40 ft.

Catch Points are frequently provided in running lines on fairly steep rising gradients to derail any vehicles which may happen to break away from a train and run backwards in the wrong direction. Single switch tongues are used for this purpose and are placed in the cess rail.

These catch points are of an automatic type in that they are normally held by a spring in the position to derail vehicles travelling in the wrong direction, whilst a vehicle passing through in the right direction closes the switch rail against the stock rail. The switch rail returns to the open position after the passage of a wheel, under the action of the spring.

The choice of which type of catch road should be used in any case is controlled by the Ministry of Transport requirements which depend chiefly on the gradient of the siding, and whether or not locomotives enter the siding.

Where another siding diverges from the first closely following the turnout from the main, difficulty is often found in obtaining room for catch roads for both sidings. This may be overcome by providing a double slip connection in place of the turnout from the first siding to the second.

CHAPTER IV.

MAINTENANCE.

MANNING OF LENGTHS.

Day to day maintenance of Permanent Way is carried out by the " length gangs ", consisting of a number of lengthmen under the charge of a ganger. A sub-ganger is also included in the gang to deputise for the ganger when necessary. A length gang may be of one of the following types :—

(1) A small gang of from three to five men maintaining a short length of single or double line.

(2) A larger gang, of from six to twelve men, maintaining a proportionately longer length.

(3) A gang of from six to twelve men maintaining a length which is geographically short but which embraces four or more lines of way.

(4) A " mobile gang " of considerable strength.

Each type has its advantages in particular circumstances. The first permits the ganger to make a close personal inspection without being far from his gang for long periods, and small faults in the track can be quickly found and remedied. Its disadvantage is that the gang is not strong enough to undertake without assistance the lining up of points and crossings, and is handicapped even in repairing plain line. Though formerly the commonest type, the small gang seems destined to be retained only on straightforward lengths which are easy to maintain.

The second type of gang includes a patroller. Thus the ganger, being freed from the daily duty of walking his length, is usually in personal charge of the work being carried out by the gang. The gang is strong enough to carry out all ordinary repairs unaided and can be split into two effective working parties, in charge of the ganger and sub-ganger respectively, if lighter repairs are needed in different places. The type is normally unsuitable for a single line, and for a double line length there is considerable loss of time in walking to and from the work in hand.

In the third type the walking time is diminished and supervision is facilitated by the compactness of the length, which may be very short in the vicinity of large stations. In such positions the organisation of the gang presents special features, among which are the fact that there is practically a full-time job for a point oiler with his lookout man, and the frequent calls for lookout men to serve other Departments. The loss of working time during passage of trains is usually considerable.

The fourth type gives the advantages of the large gang without the losses due to walking time. It involves the use of motor trollies, and is, therefore, economical only on lines with a comparatively infrequent train service. In this system a gang of up to about 12 men would maintain a length perhaps 16 miles. (These figures vary considerably with different localities). The gang is equipped with a trolley propelled by a petrol engine, and a trailer. These enable the men, with the necessary tools and materials, to be transported quickly to the site of their work, thus saving both the men's energy and the time lost in walking with the other types of gangs.

The usual composition of a mobile gang is a ganger, a sub-ganger, one or more patrolmen, a trolley driver, and a number of lengthmen. One or more members of the gang should be capable of driving the trolley when the appointed driver is not available. The driver should have sufficient mechanical ability to enable him to make minor running repairs to the engine and transmission, but he is not expected to undertake major repairs to the mechanism.

Motor trollies are usually signalled as a train, and this means that a trolley has to run through a block section so that the " train out of section " signal may be given when the section is clear ; men, tools and materials being set down on the way. On single lines the train staff tablet or token is carried on the trolley, and on long sections intermediate tablet instruments are often provided so that the line may be cleared thereat and a considerable amount of light running avoided.

The trolley is removed from the track at fixed points where a pair of rails are provided in the cess for it to stand on. These are frequently placed inside a garage or shelter. A simple form of portable turntable and ramps are carried with the trolley, and the operation of removing the trolley from the track is quick and easy.

DUTIES OF A LENGTH GANGER.

The work of a length ganger may be classified under three headings :—

(1) The inspection of the track and other works on his length with a view to early detection of any defect.

(2) The organisation and supervision of all work undertaken by his gang in repairing such defects, etc.

(3) The rendering to his superior Officer of those reports and returns which are required for administration, accountancy and supply of materials.

The first-mentioned duty, that of inspection, is fully dealt with on page 77, and details of the various types of work which may require to be done, either as a result of that inspection or in pursuance of instructions from a superior Officer, are set out in the succeeding pages.

To be successful in his daily routine a length ganger must give careful thought to the allocation of work between his men. He should know the temperament of each man employed under him, and should act so as to avoid any clashing or disagreement. He must know, before he comes on duty in the morning, what work he wants the gang to do and, on reaching his men, he must allot the tasks accordingly, giving each man the sort of job he is most capable of doing. A job well planned is already partly completed.

On some railways, the daily labour of lengthmen is specified by the Engineer by reference to a calendar of seasonal work, and it is only on certain days or in certain weeks that the ganger is permitted free choice of what work his men will do. On others, a length gang is required to work systematically through the length from one end to the other, doing everything which needs to be done *en route*. Elsewhere, the ganger is left free to work in his own way, except when specially instructed by his Inspector.

Owing to varying conditions prevailing on different lengths, and the differences in climate between one locality and another, any calendar is generally a compromise and it is not always practicable to adhere rigidly to it, hence Inspectors are empowered to authorise Gangers to deviate from the calendar where necessary, in the interests of efficient maintenance. Except when so authorised, or in an emergency, a Ganger must arrange his work in accordance with the calendar.

A typical calendar of seasonal work is given below :—

Week ending	Week No.	Work.
	1	Inspector's week.
	2	General repairs to track.
	3	
	4	
	5	
	6	
	7	
	8	
	9	Inspector's weeks.
	10	
	11	Greasing fishplates, adjusting expansion gaps.
	12	
	13	
	14	Inspector's week.
	15	Screening ballast, making up slack places.
	16	
	17	Cleaning ditches.
	18	General repairs to track.
	19	
	20	
	21	
	22	
	23	Inspector's weeks.
	24	
	25	Cutting grass, trimming hedges and trees, weeding.
	26	
	27	
	28	
	29	Inspector's weeks.
	30	
	31	General repairs to track.
	32	
	33	
	34	
	35	Screening ballast, making up slack places.
	36	
	37	Inspector's week.
	38	Adjusting expansion gaps and sleeper spacing.
	39	
	40	
	41	Cleaning ditches.
	42	General repairs to track.
	43	
	44	
	45	
	46	
	47	
	48	
	49	Trimming hedges and trees, repairing fences, digging fire borders.
	50	
	51	General repairs to track.
	52	

Having qualified for his position by doing all the tasks which he has now to allocate among his men, a ganger has a firm understanding of the time required for doing any particular job. He thus knows when he will have labour available for the next job, and he should make up his mind in advance what that next job will be.

He should have in his mind, or in his note-book, a number of useful occupations to which men can be diverted in certain contingencies, *e.g.* on wet days or on finishing a job with an hour to spare to the end of the day.

A ganger is required to furnish his Inspector with certain periodical returns, the most important of which is the weekly time and charges sheet for the gang. It is usual to set aside a definite period on one day of the week for this routine clerical work; other reports (*e.g.* of mishaps) and correspondence should be dealt with as they arise. It is to be recommended that a ganger prepare and keep up to date a full list of the returns of various types which are required of him, to enable him to do his work methodically, and with the certainty that he is not omitting anything. The exact nature of such a list would depend upon the locality and upon the practice of the Railway Company concerned, but a typical list is given below to show the way in which it should be set out and to illustrate the type of returns which are required :—

	To be in Inspector's Office :
Periodical Reports : Weekly.	
Time and Charge Sheet.	Monday morning.
Periodical Reports : Monthly.	
Reports that all points have been tried.	25th of month.
Reports that all drains and catch pits have been kept clear and open.	,,
Reports on encroachments during month.	,,
Reports on condition of fog machines.	,,
Reports on condition of point clips.	,,
Reports on condition of roads & bridges.	,,
Reports on condition of platelayers' cabins.	,,
Reports on condition of brakes on platelayers' trolleys.	,,
Reports on condition of mile and gradient posts.	,,
Readings and condition of subsidence posts.	,,
Number of fishplates broken in tunnels.	,,
Gauging of crossings.	,,
Riddling of stone ballast.	,,
Stock book, made up.	Every 4th Monday.
Periodical Reports : Half Yearly.	
Signature for rule books.	June 30th. / December 31st.
Periodical Reports : Yearly.	
Oiling of fishplates and bolts.	April 30th.

General Reports (*when required*).

Application for holidays.	10 days before required.
Application for free tickets.	,,
Application for privilege ticket orders.	2 days before required.
Encroachments.	Immediately.
*Broken rails.	,,
*Distortion of line.	,,
*Any other failure of way and works, floods, slips, etc.	,,
*Derailments.	,,
*Accidents to Company's or Contractor's workmen.	,,
*Accidents to members of the public.	,,
Trespassing on the line.	,,
Cattle, etc., on the line.	,,
*Fires.	,,

*Items marked " * " should be reported by wire to the Inspector at once if they are of a serious nature, as should any occurrence endangering the safety of the line. If necessary, the Engineer also should be informed.

In reporting such occurrences as derailments, broken rails, slips, etc., full details must be given in a concise manner, and care taken to see that mileages and similar information are accurate.

It must be remembered that the ganger's report, especially when made by telephone or wire, is frequently the only information on which an Inspector can decide what action should be taken in an emergency, and, therefore, the report must give a complete and accurate description of the occurrence, and should incorporate any suggestions that the ganger has to make on the method of dealing with it.

In most cases a sketch should accompany reports of occurrences affecting the track or Railway property. Such a sketch should be clear and should enable the site to be identified on a plan. For this reason the up and down roads should be marked (or, if in a siding, the siding name or number given), and the distance of the occurrence from the nearest mile post, bridge, or signal box should be indicated.

Daily Length Examination.

It is required by Rule 221 of the Railway Clearing House Standard Rules that each ganger, or other authorised person, must walk over his length of line once daily on weekdays except where special authority is issued in writing by the Engineer. The " other authorised person " is usually a patrolman specially designated for the purpose, or, if there is no patrolman and the ganger is not available (owing to holidays, sickness or other causes) the sub-ganger. When the daily inspection is made by a patrolman, the ganger must arrange to walk the length himself at least once a week, as the responsibility for its good condition remains his.

Further instructions regarding length examination on Sundays, articles to be carried when examining the length, and duties to be carried out during the examination are set out in Rules 220 and 221. The notes which follow are intended to assist in the carrying out of those Rules, but they do not in any way replace them.

The person walking the length must tighten up all keys and other fastenings which may be loose, and examine the line, level and gauge of the road, and the state of the joints. He should mark, and, if necessary, repair those which are defective. It is usual to walk once over each running line, facing the traffic on that line. Where it is safe to do so, it is generally found most convenient to walk in the centre of the four-foot way, whence a view of all keys and fastenings can be obtained and major defects in top, line and cross level readily seen. Hollow or swinging sleepers can be detected by their dull sound in treading upon them, though this is often more apparent in walking on the sleeper ends.

During the passage of trains, the opportunity should always be taken of watching the behaviour of the track and of listening for any unusual noises. Sometimes the first intimation that a ganger may have of a broken rail is the uneven rhythm of a passing train. This applies particularly in tunnels, where owing to conditions it may be difficult to see clearly.

The purpose of the daily length examination is primarily to observe and locate defects; their correction is, in most cases, a matter to be dealt with by the gang afterwards. Thus the arrangement followed in this Chapter is designed to fit in with this procedure. First will appear, in the form of questions, a list of defects which it is assumed that the ganger or patrolman should be continually seeking as he proceeds to walk his length. In the succeeding pages the methods of correcting such defects will be described.

QUESTIONS FOR A LENGTH GANGER'S GUIDANCE.

1. DAY BY DAY.

Plain Line.

Top.

Is there a good top ?
Do any sleepers need packing ?
Are any joints down ?
Is there any subsidence ?
Do any chair screws, or bolts need tightening ?
Are there any loose spikes ?
Do the rails sit properly in the chairs ?
Are the fishbolts screwed up tight ?
Are any rails broken, cracked or defective ?

Alignment.

Is there a good line on the straight and regular alignment on the curves ?
Is any slewing required ?
Is any crowing of rails necessary ?
Is the gauge right ?
Are check rail clearances correct ?
Are any fishplates cracked or broken ?
Are the expansion gaps correct ?
Are the sleepers square and correctly spaced ?
Are all the keys driven home ?
Are the alignment monuments in good order ?

Level.

Are the cross levels correct ?
Is the cant right ?
Is the run out of cant right ?
Is the proper cant maintained under traffic ?

Switches and Crossings.

Are any stud bolts or stock rail blocks loose or broken ?
Are any crossing blocks or bolts broken ?
Are all screws and bolts screwed up tight ?
Do any crossing timbers need packing ?

Track Circuited and/or Electrified lines.

Is ballast clear of rails ?
Is there any unsecured wire or metal lying near the rails ?
Are any bonds broken ?
Do any insulated fishplates require new packings ?
Is there any protection boarding standing too high ?
Are rubber mats being used or at hand in readiness ?

General.

Are there any gaps or loose wires in fences which might encourage trespassing ?
Are there any encroachments on the Company's property ?
If any excavation near or under the lines is in hand, is the track properly supported ?
Is any work proceeding which requires a speed restriction ?
Are all occupation crossing gates kept locked when not in use ?
Are oil boxes and lubricators replenished and working properly ?
Is there any water in check rail or old type boxes ?

2. PERIODICALLY — AS REQUIRED BY CIRCUMSTANCES.

Switches and Crossings (say once a week or as required by Traffic conditions.)

Do all switches work properly ?
Are all switches to gauge ?
Are any switch blades or stock rails damaged or badly worn ?
Are the stretcher rods straight ?
Are any parts of the stretcher rods loose ?
Are the slide chairs clean and oiled ?
Are the crossings properly checked ?
Is there undue wear on any crossing nose or wing rail ?
Is there any play in point chairs ?
Are the crossing timbers split or decayed or badly worn ?
Are the switches or the crossings being driven ahead or out of alignment ?
Are any rails creeping and tending to shear bolts ?
Is the flangeway correct through the crossings and checks ?
Is the outer switch rail oiled from tip to heel ?

Drains, Etc.—(As required by local needs and in anticipation of weather conditions.)

Are the drains clear and working ?
Are catchpits clean ?
Are gullies and water column sumps clean ?
Are all ditches clean ?
Has water a free passage in culverts, streams or rivers ?
Is there any scouring round abutments and wing walls of culverts and river bridges ?
Are there any springs issuing from the slopes of cuttings or embankments ?
Are there any signs of slips ?
Are the drains and troughs in cutting or embankment slopes in good order ?
Are there any cracks in the slopes ?
Is any water from outside the railway flowing on to railway property without authority ?

Structures and Roadways.

Are there any signs of new settlement cracks or movement in retaining walls, bridge piers or abutments, arches, etc. ?
Is there any loose brickwork in tunnels and arches ?
Are the manholes clear of obstruction in tunnels ?
Are the highways and approach roads, maintained by the Company, in good repair ?
Is there any immediate patching of roads and footpaths necessary ?
Are all Private Road Trespass Notices, Warning Boards and Bridge Restriction Plates, etc. in good repair, and legible ?
Are all level crossings in good repair ?
Are platforms clear of platform gauge ?
If on a curve, is allowance made for overthrow ?
Are all overbridges and tunnels clear of loading gauge by the specified amount ?
If on a curve, is additional allowance made for overthrow ?

Sidings.

Do four foot ways and six foot ways need clearing out ?
Are all buffer stops in good condition ?
Are walkways kept unobstructed ?
Is the material in and the fettle of the sidings generally satisfactory, having regard to the traffic carried ?
Is the loading gauge correct and over a straight portion of siding ?
Is the loading gauge tester true and in good order ?

Materials and Tools, Etc.

Are the men's and tool huts in a clean and tidy state ?
Are all fogmen's huts and braziers in good order ?
Are all detonator placing machines in good order ?
Is the stock of materials kept up to the standard ?
Are stocks of materials neatly stacked or buried ?
Are stacks of sleepers and other timber properly protected against fire ?
Does the stock of tools agree with the list ?
Do any tools need repairing or replacing ?

3. PERIODICALLY—AS SET OUT IN THE CALENDAR.

Fencing, Hedging, Etc.

Is grass cleared away from fences and cables ?
Is there a proper fire border ?
Are all stiles, wicket gates and level crossing gates in good order ?

Are boundary posts or rails, end of maintenance plates, etc. maintained in their correct place ?
Are all mile, gradient, subsidence, buried cable and other marking posts in good repair ?
Do any trees or shrubs on the railway or adjoining land need cutting back or cutting down ?
Is the straining gear of wire fences in working order ?
Are fence wires kept tight in hot weather ?

Greasing Fishplates, adjusting Rails and Sleepers.
Are there any defects or cracks in the rail ends apparent when the fishplates are removed ?
Are there unnecessary holes in the web at ends of rails ?
Do any expansion gaps need adjusting ?
Do any rails need anchoring ?
Is there any excessive top wear in the rails ?
Is there any excessive side wear in the rails ?
Have the nuts of through bolts in chairs been oiled ?

General Repairs to Track.
Are any sleepers split, broken or decayed ?
Are any sleepers badly chair worn ?
Do any ferrules need changing ?
Do any treenails need replacing ?
Are there any weeds in the ballast or the cess ?
Does the cess need trimming ?
Is the length clear and tidy, free of rubbish and scrap material ?

Cleaning and Renewing Ballast.
Is the ballast in good condition ?
Is there a proper shoulder on the outside ends ?
Is the track short of ballast in any way ?
Is any clay appearing in the ballast ?
Is the formation properly sloped to the cess or drain ?

Cutting Grass and Trimming Hedges.
Is the grass, etc. being cleared or burnt as quickly as practicable ?
Is it being burnt in a safe position ?
Where grass, etc. has been burnt, has the fire been completely extinguished at the end of the day's work ?

THE HALLADE TRACK RECORDER.

The Hallade Track Recorder is an instrument which produces a graphic record of the defects in the top, line and superelevation of a track over which it is carried in a train. Its essential parts are :—

(1) A motor driving a drum which carries the strip of paper on which the chart is plotted.

(2) A set of pendulums sensitive to rolling and to drawbar pull of the locomotive, connected to a pen which makes a record on the chart of any rolling of the train, and also of acceleration and braking.

(3) A second set of pendulums sensitive to side thrust only, with a pen to record any thrusts received.

(4) A third set of pendulums sensitive to vertical movement only, with a pen to record any sudden rise or fall.

The instrument is carried in a compartment immediately over the bogies in a good average non-stop train. As it is not always possible to use the same coach for all records allowance can be made, by means of damping pistons, for the different riding qualities of coaches, in order that a fair comparison may be made between records taken over the same line on successive occasions.

Fig. 33 is a sample section of the chart, from which it will be seen that four lines are produced by the instrument.

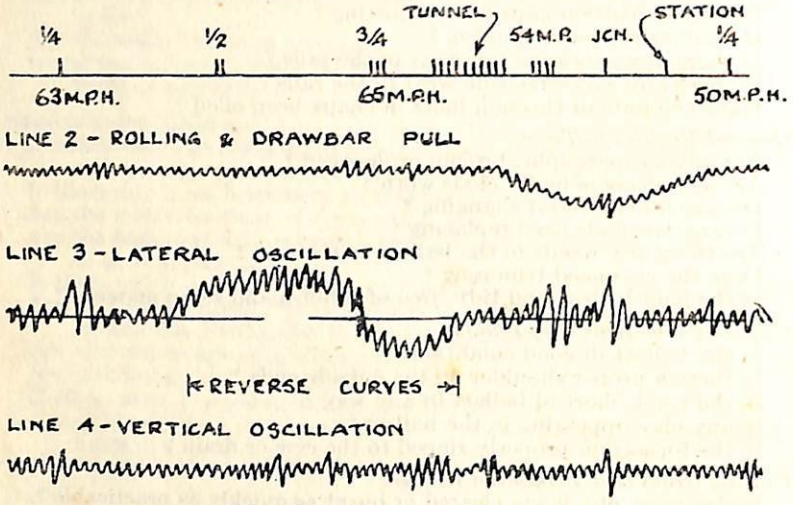


Fig. 33. Hallade Record.

The top line is a record of the features of the route, on which mile posts, stations, junctions, and tunnels, etc., are recorded by the Operator who can make the pen producing this line move sideways as the train passes one of the above features, so making a small ' kick ' in the line.

The line below this represents the rolling of the vehicle by a wavy line. The line also drops below its normal position on the chart as the train speed decreases, and rises again as the train accelerates.

The third line represents lateral oscillation of the vehicle. If the vehicle travelled without moving from side to side, this line would be straight, but this rarely occurs, except at very low speeds, and side to side motion of the vehicle causes the recording needle to oscillate about the straight line, so producing the wavy effect.

The amount the needle travels from the straight line is a comparative measure of the amount the vehicle diverges from its true path.

When the vehicle traverses a curve that has not the correct superelevation for the speed at which the vehicle is travelling, the needle will oscillate about a line to the side of its normal position. If this is noticed on any record it is a useful guidance as to whether a curve is incorrectly superelevated, as the actual speed at which the record was taken can be calculated from the known rate at which the paper unrolls from the drum, and the distance apart of the mile posts on the record. (The faster the speed of the vehicle, the closer together will be the mile post marks on the record). The speed is usually calculated at every half mile after the record is made, and then marked on the record.

From the third line, any irregularities in alignment, uneven fettling, and lengths of centre bound or end bound sleepers in the track can be located by their position on the record in relation to the mile posts.

The bottom line is a record of the vertical disturbance to the coach, and thus low or high joints, a bad top generally, or hanging sleepers will be indicated on the record and their position in the road can be discovered.

It is difficult to tell from a record the exact cause of any defect recorded, but it is possible to tell quite accurately the position of the defect.

In the past Gangers have often regarded Hallade Records with disfavour as they draw attention to the defects, but it is being appreciated now that they are a great help as they enable the worst places to be quickly located and dealt with, and successive records shew whether any improvement is being made in the road.

The records are usually dealt with first by the Technical Staff, who examine them and note the position of any defects and the probable cause. A list of these and a copy of the record are then sent to the Permanent Way Inspector who must locate the defect in the track and give it attention. The list of defects is then returned to the District Engineer with any remarks the Inspector may wish to make regarding the cause of the defects and their treatment.

A new record should be carefully compared with previous ones on the same route, and by this means, it is possible to see whether defects are being successfully dealt with, and any improvement in running being maintained.

LIFTING AND PACKING.

To keep a good " top " on a line it must be lifted wherever it is low, and the ballast must be packed firmly under the sleepers at the points where it has been lifted. Owing to the

difficulty of lowering the line under traffic, it is not usual to lower the high spots (except where platform or bridge clearances make it impossible to lift), but to bring the remainder up to level of the high spots.

Lifting.

The track may be lifted either by levers or by jacks, the latter method being the most satisfactory. Levers are usually of timber, tipped with iron, and are provided with a block for spreading the load over the ballast under the lever " heel ", or fulcrum. They are worked by two men and the lift may be held by placing packings under the rail. The levers must, of course, be worked in bays from which the ballast has not been opened out. In the interests of safety, levers should not be worked across the four-foot way.

In lifting with jacks, they should be placed under the rail on the outside, except where the presence of a conductor rail makes it necessary to place the jacks in the four foot, in which case they should be of a design which provides clearance for passing wheel flanges, in order that they will not be foul of traffic if they could not be released in time. They should not be placed under a joint if there is any risk of crippling it.

When lifting under traffic, no lift must exceed three inches, even if there is a speed restriction in operation. In lifting a section of line a start should be made at the " running-off " end of that section, and the lifting should proceed in the opposite direction to traffic, in order that a train passing over the section during the operation may rise on to the lifted portion. (On a single line, if there is a gradient, the lifting should be started at the downhill end). During the work a run-out not less than 60 feet must be maintained to permit trains to mount the lifted section. On high-speed lines where a speed restriction is not in force, the run-out should not be less than 60 feet (on the G.W.R. 66 feet) *per inch of lift*. In practice this means that a lift of more than one inch should not be attempted without a speed restriction. In all cases the Ganger must consider whether the margin between trains gives him time to pack such a length and, if not, whether to impose a speed restriction in accordance with Rule 217(g).

When both rails have to be raised they should be lifted at the same time, care being taken to prevent passing trains from being canted towards one another across the six-foot way. On curves it is usual to set one rail to the correct grade, and to put the other to give the required superelevation.

In lifting under complete possession, the amount of lift is limited only by the travel of the jacks.

Local defects in ' top ' may be observed by placing the eye nearly at rail level. Generally, however, when the track is to be lifted, pegs are fixed by the Technical Staff at distances apart which may vary between 90 ft. and 180 ft., the top of each peg indicating the proposed rail level, or the level of either the high or low rail if the track is curved, opposite to the peg.

The track is then lifted to the new level opposite each peg, a straight edge and spirit level being used, by jacking up the track and placing ballast under the sleepers to the required amount. It is usual in lifting to raise the track slightly higher than the final level to allow for the sleeper beds consolidating under traffic, though this must not be done if structure clearance would be encroached upon. The amount to be allowed for consolidation is a matter for judgment in each case, it depending generally on the nature of the formation and the quality of the ballast.

It is necessary to lift the intermediate track to a constant grade between the pegs, and for this purpose lifting boards are used. These boards, about 8 feet long and 1 foot deep are used, one being placed on the track opposite one peg, and another on the track opposite the following peg. The underside of each board is put to the same level as the top of the peg by placing it on a step ladder. Then the third board is placed on the intervening track at intervals and the track then lifted and packed so that the tops of the three boards are in one plane as seen by placing the eye at the level of the top of the first board, when the third board should just obscure the view of the second board, as shewn in Fig. 34. All these boards must be kept level in use.

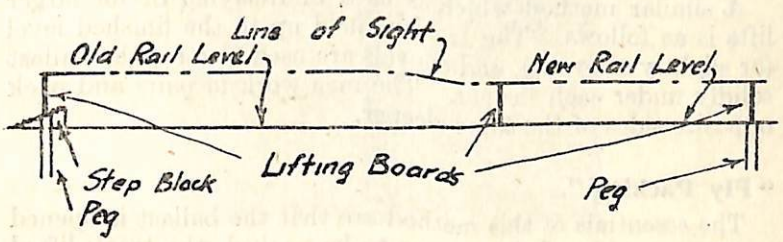


FIG. 34. USE OF LIFTING BOARDS.

Before lifting is started, two men, one with a bar and one with a keying hammer, should go through the length to ensure that the rail is sitting properly in the chairs. Fastenings should also be tightened.

Packing (General).

In order to spread the load from the rail to the formation, about twelve to fifteen inches on each side of the rail should be firmly packed and the middles and ends merely loosely packed with a shovel. If the sleeper bears in the centre (*i.e.* is " centre-bound ") the track rocks under traffic causing vehicles to roll from side to side, while if it bears on the ends the sleepers may break under the chairs.

By Beater.

The beater is a pick with one blunt tee-shaped end for driving the ballast under the sleepers and timbers. On each side of the sleeper to be packed the ballast is opened out to the level of the underside of the sleeper. Then, while the jacks hold the road up to the correct height, the ballast under the sleeper is loosened as necessary with the sharp end of the beater and then beaten up tight from both sides with the blunt end, the strokes being kept as nearly horizontal as possible. Care must be taken to avoid forcing under the sleeper any stones so large as to cause uneven bearing and to avoid striking the edges of the sleepers and timbers. The disadvantages of the method are that it is impossible entirely to avoid damage to the sleepers, which get rounded underneath, and that if the ballast under the sleepers is shallow the formation may be furrowed. It also tends towards irregularity in packing owing to the difference between the work of different men.

Pneumatic, electric, or petrol driven, tamping machines may be used instead of beater picks for packing sleepers in this way. When using machines, however, it is not necessary to open up the ballast.

A similar method which is used in Relaying or for larger lifts is as follows. The track is held up to the finished level (or slightly above it), and shovels are used to force the ballast solidly under each sleeper. The men work in pairs and pack opposite sides of the same sleeper.

" Fly Packing ".

The essentials of this method are that the ballast is opened out on one side of the sleeper to be packed, the track lifted temporarily some inches above its correct level and a quantity of chippings spread under the portion of the sleeper which should transmit the load, the track being then lowered upon the new beds. This method is also known as ' shovel packing ' and is essentially suitable for the small lifts required in fettling. As hitherto practised on certain British Railways it has

depended upon the skill of the Ganger in estimating the amount of chippings necessary under each sleeper. This need for estimating is now being replaced by the more scientific method described in the next paragraphs, which was introduced in France, and which was tried with very good results on the L.M.S.R., and is now being used considerably on other Railways.

MEASURED SHOVEL PACKING.

The amount by which the bed of any sleeper must be raised to give a good top has two components, which must be separately measured :—

1. The amount that the rail itself is down below the true grade when unloaded, as measured by boning through between ' high spots ' on each side of the slack length, and

2. The amount the sleeper is depressed relative to the ballast around it, on the passage of a train (or in other words the depth of the void underneath a hanging sleeper when unloaded).

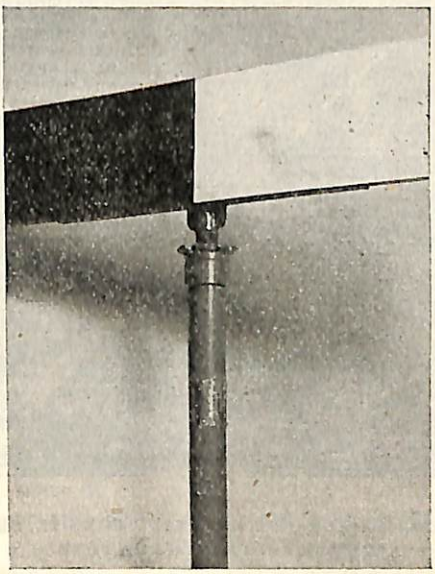


FIG. 55. PART OF INTERMEDIATE SIGHTING BOARD SHOWING ADJUSTMENT AND SCALE.

In France the first amount is measured by a telescope and two targets, and the second by an instrument called a dansometer. This consists of a small tripod, straddling the sleeper end and supported on the ballast, which carries a spring loaded

plunger resting on the sleeper. The plunger has a friction collar which moves on the plunger as the sleeper is depressed under traffic so recording the depression under the sleeper when the plunger comes to rest.

This apparatus gave good results but was cumbersome to use, and the L.M.S.R. with the assistance of Messrs. Abtus, Ltd., made experiments to simplify it, the outcome of which was the Abtus Sighting Boards and Voidmeter. These are now in considerable use in this country.

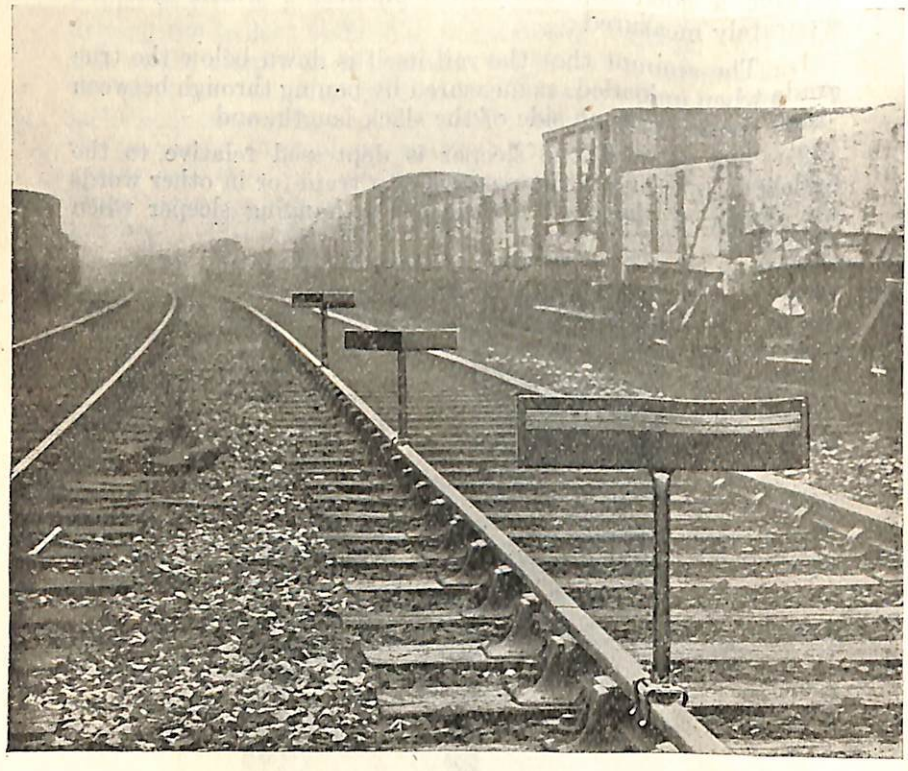


FIG. 36. SIGHTING BOARDS ON RAIL READY FOR USE, SET CLOSER THAN NECESSARY, TO SECURE PICTURE.

The sighting boards consist of a set of three, known as Sighting, Intermediate and Target Boards respectively, as illustrated in Figs. 35 and 36.

Each board is provided with a base to bear on top of the rail, two spring clips which clasp the sides of the rail head, and a small spirit level for setting up.

The Sighting Board has a horizontal brass edged sighting slot about 1/64th″ wide for almost its full length, the slot being exactly 2′ 0″ above the base, or rail level.

The Intermediate board is adjustable for height by a collar nut and is provided with a scale calibrated in ' packing units ' and index on the post. The board is painted black one end and yellow the other and the upper edge is 2′ 0″ above base, when the index is at its lowest point, marked " 0 " on the scale. A small recess or notch is cut in the centre of the upper edge to facilitate sighting.

The Target Board is similar to the Sighting Board except that it has no slot but is painted black and yellow, quartered, the horizontal margins shewing a sharp line, also 2′ 0″ above the rail.

To measure depression of sleepers under traffic the " Abtus " Voidmeter takes the place of the Lemaire Dansometer and one pattern of this is shown in Fig. 37. An older pattern with a horizontal pointer multiplies movement by 2, but in each type one small division on the scale represents one packing unit.

The instrument is clamped to a stake driven in to the ballast close to the sleeper, so that the ball shaped end of the lever on the instrument is in contact with the top of the sleeper. An idle friction tight pointer is then pushed against this lever. When traffic passes the ball shaped end of the lever follows the depression of the sleepers, under spring action, pushing the friction pointer ahead, and returning to its original setting when traffic has passed but leaving the friction pointer at the point of greatest movement. The number of divisions and fractions of divisions between the two points shews the extent of sinking of the sleeper under traffic, in measured packing units.

A measured packing unit is a quantity of graded stone chippings which will, when placed over a fixed area under a sleeper of given width raise it by a definite amount, and all measurements in this system of packing are stated in " Units " or " Canisters ". The measure or canister used has a capacity related to the area of one packing which is 300 square inches for a 10″ sleeper and 360 square inches for a 12″ joint sleeper, both of these areas giving a length of packing of 2′ 6″. A slot in the side of the measure is the mark for a charge or Unit for a 10″ sleeper and the full levelled measure is the charge or Unit for a 12″ sleeper.

This " Unit " is the basis of Measured Packing and the whole system is built around it. One Unit represents 1/16″.

In using the " Abtus " apparatus particular attention should be given to the following points.

When sighting or boning boards are set up they are roughly levelled by the spirit levels attached but they may not all be quite level when sighted and the person sighting should have the Target and Intermediate boards tilted so as to bring their sighting lines in register with the slot. It is also very important that when fixing boards on rail and when adjusting them even very slightly that the base be pressed down with the foot to ensure proper bearing on the rail top.

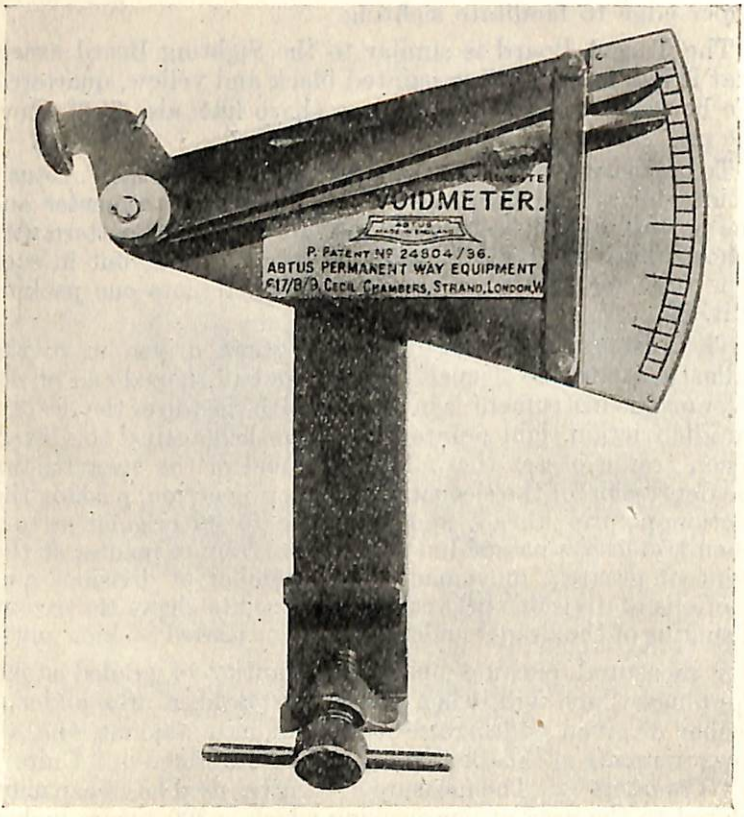


FIG. 37. LATEST TYPE OF VOIDMETER WITH 4 TO 1 SCALE.

In the fixing of Voidmeters the stakes or pickets to which they are clamped must be driven far enough to make them quite firm and without shake and they should be as nearly upright as possible and in such a position that the bearing points on the sleepers are near the centre and just clear of the end of the chair. When clamping a Voidmeter to a stake the spring pointer should be held back so that when fixed and bearing on a sleeper it is slightly back of centre and clear

of the end stop. This clearance is important as a sleeper on a well packed track rises slightly from its bed when a locomotive or heavy vehicle bends the rail between the two sleepers behind it. This movement is not recorded nor should it be but if there is insufficient clearance between pointer and back stop the instrument will be damaged.

Before starting on the measuring and packing of a length of track all fastenings must be gone over and screws or bolts tightened, plugging as necessary; and any sleepers hanging on the rail, even to the extent of allowing a small knife blade between the foot of the rail and the chair, must have keys driven out and redriven with the sleeper held hard up to the rail by bar, using new keys where necessary.

When these details are in order the top of the rail is eyed and two high spots, not more than 120′ and not less than 90′ apart (unless a very sharp curve enforces a shorter length) are marked.

When the high spots have been selected on a rail the cross level at each point should be checked, making allowance for the correct cant on curved track and any discrepancy measured. One method of doing this is by the " Abtus " cross-level transfer gauge, this having a movable cam at one end which is turned in the direction required to bring the level bubble exactly to the centre of the tube when the difference between the two rail levels is read directly from the scale provided.

With this tool plus or minus difference is shewn and the other end of the gauge, which is insulated to avoid interference with Track Circuits, has an adjustable plunger divided in $\frac{1}{8}$ths of an inch which is set up to the correct superelevation on curved track. $\frac{1}{8}$″ is equivalent to two units.

The other method is by ' shimming ' with the special " Abtus " shim sets, which consist of 2 sets of four steel shims having thickness of $\frac{1}{2}$ — 1 — 2 and 4 units of chippings which allows of variations from $\frac{1}{2}$ to $7\frac{1}{2}$ units, by $\frac{1}{2}$ units, being measured. When the " Abtus " cross level transfer gauge is used only one rail is sighted by the boards, the level of the other rail being measured at each spot where boards have been used, including the sighting and target boards, and the figures chalked on the first rail corrected by adding " plus " readings or deducting " minus " readings and the figure so found chalked on the sleeper at the second rail. Great care must be taken that the bubble of the level tube is exactly centred at each reading otherwise a wavy top will result.

When " Abtus " shims are used, one rail is sighted for the " high spots " and at each the ordinary straight edge or levelling rule is applied, using the stepped cant block or other means of measuring cant if on a curve. If the unsighted rail shows lower than the " high spot " the straight edge should be packed up with one or more shims until the bubble is centred and the sum of the numbers stamped on the shims used chalked on the sleeper end. The second high spot is similarly dealt with and the top is then sighted by the boards as before but, when setting up the sighting and target boards, they should be packed up on the correct thickness of shims as shown by the chalked figures found by cross levelling.

In using the spirit level when cross levelling it is of the utmost importance that the greatest care should be taken to ensure correct levelling and if a loose pocket level is used it should be reversed on the straight edge at each measurement if it does not centre accurately. Straight edges with built in bubble tubes should be checked at frequent intervals during changeable weather, and, if found to be out, they should be corrected before use.

Ordinary straight edges should also be checked for truth at intervals.

Should it happen that the rail being levelled opposite a " high spot " is higher than the datum or first rail the shims should be used under the low end and the boards on that side given the appropriate shimming when sights are taken. After the first length is done the sighting board is always erected on the spot occupied by the target board on the previous length dealt with so that continuity of " top " is ensured.

Care must be taken when using the sighting boards on a curve to check the superelevation of the track between the two high spots selected. For instance, if two high spots are selected on the high rail there may possibly be a point in between where the superelevation is so low, that the amount the high rail should be lifted to give the correct superelevation will be more than the amount measured at this point by the sighting boards. If this does occur, this point must be treated as a high spot, and the target board fixed here, with packing equal in thickness to the deficiency of superelevation under it.

Similar circumstances may arise if two high spots are chosen on the low rail, and there happens to be a point in between where the superelevation is appreciably more than it should be.

Lowering of the track should be avoided wherever possible and the foregoing instructions are based on lifting to a true top.

If, however, raising is not possible owing to tight structures the track is better lowered throughout a length sufficient to clear the obstruction with proper gradients and, when consolidated, the measured packing method applied.

When all sighting has been done, or while it is in progress if the strength of the gang permits the condition of the sleeper beds can be found by the voidmeters. The process consists of first sounding the sleeper by striking it with the end of a bar, preferably the head end, near the chair, the bar being allowed to drop on the sleeper rather than it being driven down. Sleepers which are "hanging" are readily detected by the sound given when struck as described and these sleepers should be marked in chalk with a cross. When a sufficient length for say, a day's work has been thus sounded and marked on both sides of the track, voidmeters are applied and readings are taken after the passage of a train, these being taken in good work to the nearest $\frac{1}{4}$ division. The length of track will then show figures for "top" on every 4th or 5th sleeper and voidmeter figures on each sleeper where movement has been measured. The "top" figures should then be averaged out where there are differences between adjoining sighted spots. Thus if one reading shows "1" and the next "2" intermediate sleepers would have "$1\frac{1}{4}$" — "$1\frac{1}{2}$" — "$1\frac{3}{4}$" marked on them in that order or, if the difference is say between "1" and "3" the three sleepers between would be marked "$1\frac{1}{2}$" — "2" and "$2\frac{1}{2}$" in that order.

After this is done, where there are two figures chalked on sleeper ends, one from sighting or from shim measurement and one from Voidmeter reading, they should be added together and the sum chalked on the sleeper end, the original figures being scored through to avoid error when packing.

When all measurements have been taken and marked up packing is commenced. Opening out, if not already done in intervals when waiting for traffic to operate the Voidmeters, can be done and in this method of packing as in ordinary shovel packing, two sleepers are packed from one opening so that, where every sleeper has to be dealt with, only each alternate space needs opening out. Where short fishplates are used or where joint sleepers are less than 10″ apart the space under a joint should not be opened. Each space opened must be cleaned out slightly below the sleeper bed, and for a distance of about 18″ from either side of the rail so that room will be made for using the packing shovel without risk of material other than the measured quantity getting under the sleeper. When a sufficient length has been prepared the track is raised for insertion of the chippings, and this is best done by a trip jack as, after packing, the track can be dropped

quickly and so partly set the bed of new chippings. The amount the track is raised should not be much more than $1\frac{1}{2}$" so as to avoid straining fastenings and when it is made packing is started by measuring the requisite number of canisters or fractions of canisters of material on to the shovel, one at a time and inserting it clearly under the sleeper, taking care to place the quantity evenly over the full width of the sleeper for a distance of 15" on either side of the centre of the rail and levelling with back of shovel when all placed.

In this method of packing it will help the accuracy of the work if a small gauge stick about 3" x 1" x $13\frac{1}{2}$" long is used to chalk a mark on the corner of the sleeper at $13\frac{1}{2}$" from either side of the rail.

The advantage of Measured Packing over the rule of thumb methods is that by the former every sleeper is given its proper bearing and the top can be more accurately set then by simple " eyeing in " without other aids.

Although the method takes considerably longer than ordinary shovel packing, it is quicker and less laborious than beater packing, and the equality of bearing which is obtained when a track with a firm formation is so treated results in such a good top, that much less frequent packing is necessary. It is often found that track which has been measured packed will stand for over a year before it needs packing again, which means a considerable saving in time spent on packing.

Measured shovel packing is not generally economical on tracks where the formation is soft, nor should it be used for lifts of more than 8 units unless these occur only over short lengths of 3 or 4 sleepers. Track requiring more than this amount of lift may be dealt with in this way, but it will generally require a further packing in 2 or 3 months.

The method is not really suitable on tracks ballasted with screened pit gravel, or gravel and sand, but it is efficient and economical on tracks ballasted with broken stone or ash.

The most suitable packing material is broken stone chippings clean and free from dirt of such a size that all material passes a screen with $\frac{1}{2}$" mesh, 50% by weight being retained on a screen with $\frac{3}{8}$" mesh, and the remainder being retained on a screen with $\frac{1}{4}$" mesh.

The packing shovel used has to be of special type and on the L.M.S. the standard has a blade 10" long x 9" wide made of 16 S.W.G. steel sheet. This blade is slightly hollow and is rivetted to a solid forged palm on the socket, this extending two inches back in the plane of the blade by a solid neck then rising in a " swan neck " to the socket for the shaft, the whole being about 4' 0" long.

The man power required for Measured Packing varies, of course, with that available but the work can be, and is quite well done by a 3-man gang. Sounding of sleepers and Voidmeter settings and readings can be carried out by the two men left when the Ganger is walking his length, but sighting or boning should be done by the Ganger, one man acting as lookout if circumstances make one necessary. Cleaning out is done by all hands and actual packing by the Ganger, one man measuring and feeding chippings and the other maintaining the chipping supply from storage bins and taking a hand with the jack if available.

With a 4 or 5 man gang the procedure is the same but the work may go on in any section while the Ganger is walking his length, and, with the larger gang, clearing out the back-filling and boxing up can be done immediately ahead and behind the packing.

ALIGNMENT.

Where pegs are fixed, the first consideration must be to keep the track at the prescribed distance (usually 3 feet to the outside edge of the rail) from those pegs.

Except on newly-constructed railways, pegs are not usually available on straight sections, where the alignment must be maintained by eye. The Ganger should send about six* men on some three or four rail-lengths ahead of him, walking clear of the rails. One of them should drag his bar along the head of one rail in order that the Ganger, standing erect astride of the rail, may stop the party when they reach the centre of a kink. He should then tell them which way to slue and they should proceed to open out the ballast round the ends of the sleepers on the appropriate side. The Ganger should then place a small piece of stone on the rail as a marker and return to a point from which he can "eye in" the line. The Lengthmen divide into two groups for the two rails, and, thrusting the pointed end of their bars into the ballast behind their rail, they lever it over as directed. They should take care that their bars have a firm hold before pulling their full weight. The Sub-Ganger or other leading man should call out to keep the pulls in unison. On some underbridges the depth of ballast is reduced and there is frequently a layer of asphalt below it which may be punctured by the points of bars. Great care should, therefore, be exercised in sluing at such points. On flat-bottomed track, tups or track liners are sometimes used instead of bars in such circumstances.

*If the Gang is of less strength than this it is best to borrow from the next Gang, but the use of track liners enables the work to be done with quite a small gang.

The correction of faulty alignment of curves is fully dealt with below, while on many curves the processes there described are rendered unnecessary by the existence of permanent pegs or " monuments ". The " eyeing-in " of curves is, therefore, only necessary between pegs or chord points, although it is true that an experienced Ganger can eye in a long curve with a considerable degree of accuracy. The process of sluing a curve by eye is similar to that described above except that on sharper curves the Ganger may need to stand rather nearer to the pulling squad.

The amount of " eyeing-in " between pegs can be reduced by the method known as quartering. On p. 204, it is shewn that for a curve of uniform radius the versine on a chord of length L is 4 times the versine on a chord of $\frac{L}{2}$.

After the track has been set to a line opposite the pegs, therefore, a string line should be stretched between points on the rail opposite adjacent pegs, and at a point midway between these two points the track should be slewed so that the versine is $\frac{1}{4}$ of that measured at an adjacent peg on a string line stretched between the pegs on either side.

This method cannot be used on transition curves.

Before starting any sluing, it is as well to tighten up the fastenings and keys. The gauge should be checked before sluing, lest a kink be put in the opposite rail.

On curves where no pegs are fixed the following methods can be used to correct or improve alignment, when a complete realignment is not necessary or possible. A complete realignment would be carried out by the Technical Staff.

1. Averaging.

To find the amount of the slue necessary to correct a local kink in what should be a regular curve it is only necessary to mark out five points on the rail, the middle one being, as nearly as can be judged, in the centre of the defect. If the string is marked, by knots or tallies, at the ends and mid-point of the chord-length, it is only necessary to mark point 3 on the rail, *i.e.* the point at the centre of the defect. The spacing of the points should be half of the length of the chord which it is proposed to use. Versines should then be taken, as shown in Fig. 38 at marks 2, 3 and 4. The three versines so obtained should be added together and the result divided by three. The difference between this *average versine* and the actual versine measured at mark 3 is the amount of the slue required at point 3 only. If the calculated average is more than the measured versine, as in the case illustrated in Fig. 38A, the slue should be outwards ; if it is less, as in Fig. 38B, the slue should be inwards.

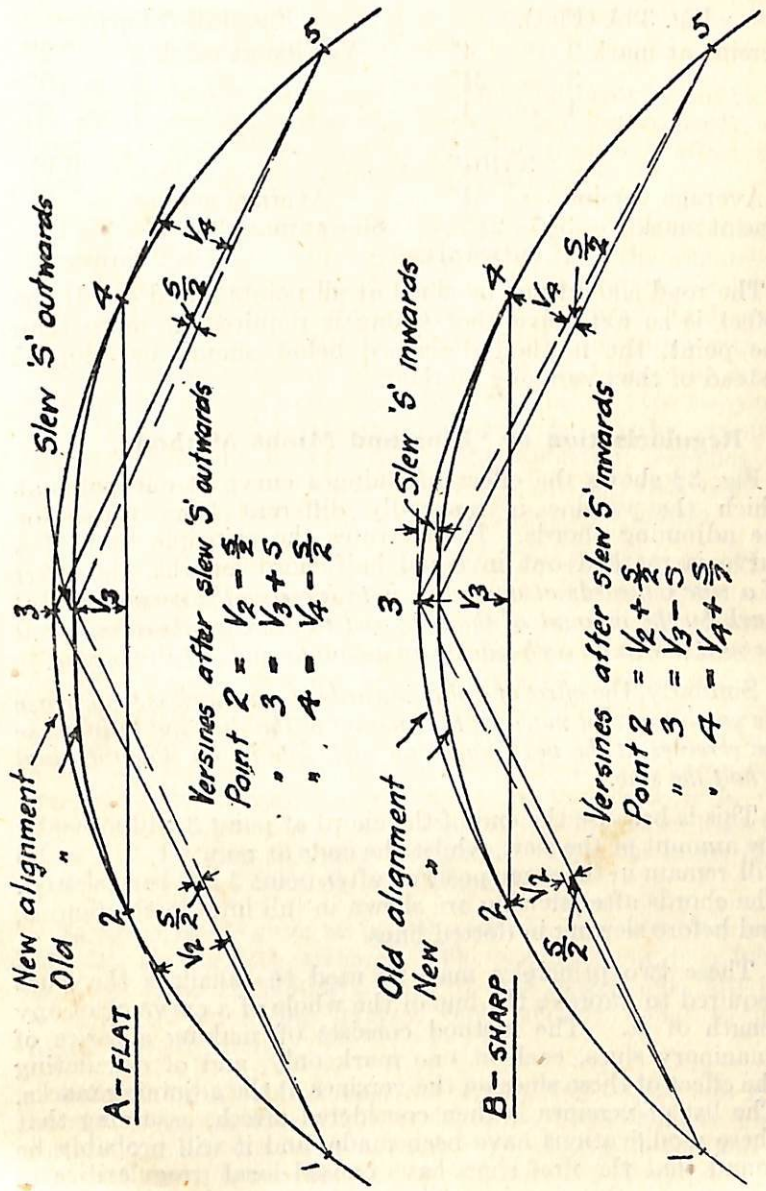


FIG. 38. EFFECT OF SLEWING ON VERSINES.

The calculations required in order to deal with the two samples of defective curve shown in Fig. 38A and 38B are given below :—

Fig. 38A (Flat).		Fig. 38B (Sharp).	
Versine at mark 2	= 4″	Versine at mark 2	= 2″
,, ,, 3	= 2½″	,, ,, 3	= 5″
,, ,, 4	= 4″	,, ,, 4	= 2″
3)10½″		3) 9″	
Average versine	= 3½″	Average versine	= 3″
Slue at mark 3 = 3½″—2½″		Slue at mark 3 = 5″—3″	
= 1″ outwards.		= 2″ inwards.	

The road should not be slued at all points 2 and 4. If the defect is so extensive that sluing is required at more than one point, the method described below should be adopted instead of the averaging method.

2. Regularisation or 'Plus and Minus Method'.

Fig. 38 shows the effect of sluing a curve at one point at which the versine is markedly different from those for the adjoining chords. It illustrates the principle that, if a curve is marked out in equal half-chord lengths, the *effect of a slue outwards at one mark is to increase the versine at that mark by the amount of the slue and to decrease the versines at the next marks on each side by an amount equal to half the slue.*

Similarly, the *effect of a slue inwards at one mark is to decrease the versine at that mark by the amount of the slue and to increase the versines at the next marks on each side by an amount equal to half the slue.*

This is because the end of the chord at point 3 will move by the amount of the slew, whilst the ends at points 1, 2, 4 and 5 will remain in the same position after point 3 has been slewed. The chords after slewing are shewn in full lines in the figures, and before slewing in dotted lines.

These two principles may be used to calculate the slues required to improve the line of the whole of a curve or of any length of it. The method consists of making a series of imaginary slues, each at one mark only, and of calculating the effect of these slues on the versines at the adjoining marks. The list of versines is then considered afresh, assuming that these modifications have been made, and it will probably be found that the first slues have caused local irregularities to appear at other marks. The road is now imagined to be slued at these marks, the list of versines being again revised to comply with the effect of such slues.

The process is repeated until the list of versines becomes sufficiently regular. (This condition may be either one in which all the versines are almost or exactly equal, as in a circular curve, or in which they show a constant increase or decrease, as in a transition curve).

This method is really one of " trial and error ", but it has the great advantage that the " error " is only on paper, and that the " trial " does not involve the time and effort of a gang of men, but only a simple calculation.

The table given on p. 100 illustrates how the calculation should be set out. The second column gives the versines as actually measured on the site, and a number of other columns are ruled to provide for the imaginary trial slues. Each group of three bold figures entered in these columns represents the three versines which are altered by one trial slue, the centre figure being altered to the amount of the slue and the two outer ones being altered in the opposite direction to the extent of half the amount of the slue. The unaltered versines are brought forward into each column in turn in order that the current position in each stage may be seen at a glance.

As each imaginary slue is made, its amount should be entered in the broad column at the extreme right, opposite the one mark where it is assumed to be made. An outward slue is preceded by a " plus " sign and an inward slue by a " minus " sign. Finally, when the list of versines has been satisfactorily " regularised ", the successive imaginary slues at each point are added up to give the net slue required to be made on the site. (It should be remembered that a slue preceded by a minus sign should be deducted from one preceded by a plus sign. If the minus slue is greater than the plus slue, the plus slue must be deducted from the minus slue, and the resulting slue will be a minus slue).

In the example given on p. 100, a satisfactory curve has been reached at the fifth attempt. The resulting curve is fairly uniform between points 5 and 10 and passes out into the straight by transition curves, each roughly equal to five half-chords in length.

Before the calculated slues are carried out on the site it is necessary to consider whether clearances from bridges, platforms, signals, etc., are adequate to permit them, and if they are not it is necessary to try a fresh realignment scheme. In the same example a fairly satisfactory curve would be obtained by a $-\frac{1}{2}''$ slue at point 3, a $+1''$ slew at point 7, a $+1''$ slew at point 10, and a $-1''$ slew at point 13.

Half-Chord No.	Existing Versines.	Versines after trial slues. 1.	2.	3.	4.	5.	6.	7.	Amount of Slue. (+ outwards; — inwards).
1	1/8″	1/8″	1/8″	1/8″	1/8″	1/8″	—	—	—
2	5/8″	5/8″	5/8″	15/16″	15/16″	15/16″	—	—	—
3	2 1/2″	2 1/2″	2 1/2″	1 7/8″	1 7/8″	1 7/8″	—	—	— 5/8″
4	2 1/2″	2 1/2″	2 13/16″	3 1/8″	3 1/8″	3 1/8″	—	—	
5	3 3/4″	4 3/8″	3 3/4″	3 3/4″	3 3/4″	3 3/4″	—	—	— 5/8″
6	5″	3 3/4″	4 1/16″	4 1/16″	4 1/16″	4 1/16″	—	—	— 1 1/4″
7	3 3/8″	4″	4″	4 5/16″	4 5/16″	4 5/16″	—	—	
8	5″	5″	5″	4 3/8″	4 3/8″	4 3/8″	—	—	— 5/8″
9	4 3/4″	4 7/16″	4 7/16″	4 3/4″	4 7/16″	4 7/16″	—	—	
10	2 1/2″	3 1/8″	3 1/8″	3 1/8″	3 3/4″	3 3/4″	—	—	+ 5/8″ + 5/8″ = + 1 1/4″
11	3 7/8″	3 9/16″	3 9/16″	3 9/16″	3 1/4″	3 1/4″	—	—	
12	2 1/4″	2 1/4″	2 1/4″	2 1/4″	2 1/4″	2 5/8″	—	—	
13	2 1/2″	2 1/2″	2 1/2″	2 1/2″	2 1/2″	1 3/4″	—	—	— 3/4″
14	0″	0″	0″	0″	0″	3/8″	—	—	

Fig. 39 illustrates a convenient method of adjusting versines by the use of squared paper. The versines are plotted in the form of a graph which gives a 'picture' of the curve and is useful for a long curve, as it enables the points which require adjustment to be picked out quickly without the need for examining a long list of figures. The 'plus' and 'minus' alterations are then a matter of counting squares, as will be seen from the figure.

The example shewn is part of a reverse curve, and the effect of a slue at a point adjacent to the reversal is illustrated, and should be carefully noted. It can best be remembered in the following form:—'A slue to alter the versine at any point towards the top of the paper, will alter the versines at the adjacent points towards the bottom of the paper, by half the amount of slue, and a slue to alter the versines at any point towards the bottom of the paper, will alter the versines at the adjacent points towards the top of the paper, by half the amount of the slue.

For a simple or compound curve this amounts to the same as the rules given on p. 98.

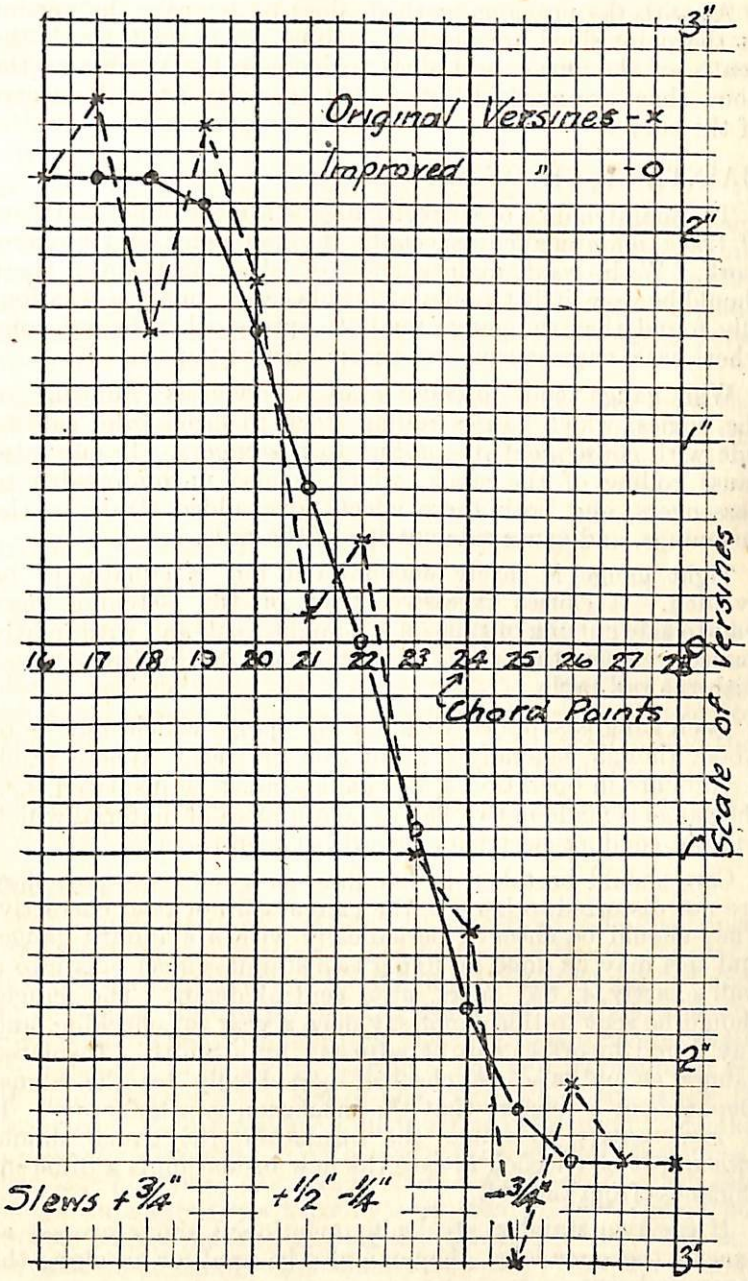


FIG. 39 ADJUSTMENT OF VERSINES.

As with the previous method, slues to decrease the versine at the point slued are marked ' minus ', and are towards the centre of the curve, and slues to increase the versine at the point slued are marked ' plus ' and are away from the centre of the curve.

MAINTENANCE OF GAUGE.

The maintenance of correct gauge is a most important part of track maintenance especially through point and crossing work. With good maintenance of chair fastenings there should be very little trouble with wide gauge, but it is occasionally found that the gauge tends to spread when heavy, long wheel-base, engines run over sharp curves at speed.

Wide gauge tends to cause what is knwon as ' hunting ' of the bogies, which causes rolling stock to lurch from side to side with consequent discomfort to passengers. It may also cause rolling of the stock, which is also uncomfortable to passengers, and both these effects give added strain to the fastenings, and cause side cutting of the rails.

Tight gauge is rarely encountered but is equally to be avoided. It causes excessive strain on the fastening, may lead to side cutting of rails on a straight road, and with lightly loaded vehicles the wheel tread may not be in firm contact with the rail table.

Each gang is supplied with a 4′ 8½″ gauge which may be of wood, though generally it is of iron or steel. Where track circuits are in operation 4′ 8½″ gauges must be insulated, *i.e.*, the gauge is made in two halves, and a piece of material which will not conduct electricity placed between them.

Care should be taken in handling gauges to see that they are not distorted, otherwise the gauge will not read correctly. They should be checked periodically with a standard gauge, and this may be done by fixing two stainless steel pins into a wall exactly 4′ 8½″ apart, at a central depot. The gauges should be sent to this depot say once a year for checking, and any found incorrect can be adjusted by a Smith. Insulated gauges should also be checked periodically by the Signal Department to ensure that the insulation is satisfactory. If it is necessary to renew the insulation, the gauge should afterwards be checked in case the new insulation is a different thickness from the old.

If the two stainless steel pins mentioned above are set at exactly the same level, they can also be used for checking the Genger's levels.

A reliable sign of distortion of gauge is afforded by the timber on the inside and outside edges of the chair. At one edge

the timber will be crushed slightly and at the other, a slight depression, which was the original chair seating, will be visible. The Ganger should not, however, rely entirely on this, but should periodically check the gauge of the track with the testing gauge provided.

When the gauge is found to have become incorrect it is necessary to move the chairs on the sleepers to adjust it. It is usually found that error in the gauge is caused by distortion of the fastenings on one rail, those on the other rail remaining sound. The adjustment, therefore, should be made on the side where the fastenings are strained, and the old chair fastening holes must be securely plugged before fresh holes are drilled as described on p. 34.

It is often desirable to remove the fastenings and draw the timbers to one side by 3″ or so, and bore fresh holes for the chair fastenings. This ensures that the fastenings are in sound timber.

MAINTENANCE OF CHAIR FASTENINGS.

Treenails and Spikes.

The spike in this type of chair fastening must be kept tight by blows with a keying hammer. When a spike becomes too loose to be tightened thus, it is necessary to renew the treenail and it is advisable when doing this to dip the spike in creosote before driving. This retards the decay of the treenail and the rusting of the spike. The treenail should be driven until it is flush with the top of the hole in the chair before the spike is inserted.

Chairscrews.

These must be tightened from time to time, a box spanner being used for this purpose. The handles of the box spanner must not be lengthened or too much force will be applied and the thread in the sleeper will be destroyed. When a chair-screw is tightened so much that the head bears on the chair it is necessary to renew the ferrule. The new ferrule must be left standing about $\frac{1}{4}$″ out of the chair when the screw is reinserted. Before placing a chair screw in position it should be dipped in creosote. With every type of chair fastening, when it is necessary to move a chair or a sleeper, or when the hole in the sleeper has become worn, the old hole should be plugged with a hardwood plug dipped in creosote, and the new hole then bored. For chair screw holes however a new method of reconditioning known as the " Metospir " method, has been evolved, which consists of placing a new thread in the old hole. This thread is made of a strip of metal which is

wound into a spiral shape on a special tool. This tool with the metal strip wound on it is then screwed into the hole, and the tool withdrawn, leaving the metal strip in the hole ready to take the chair screw. A special compound known as 'Philplug" is extensively used now for plugging screw holes. The compound sets hard in the holes, and can be re-bored. If the screw is to be refixed in the same position a little Philplug is put in the hole and the screw replaced.

Through Bolts.

The nut of this type of fastening must be kept tight by means of a box spanner in a similar manner to chair screws. It is necessary, however, in this case to ensure that the thread on the through bolt is kept lubricated, as if this is not done it will be found difficult to tighten the nut. This is done by placing a small quantity of oil on top of the nut when they are tightened.

They should be tightened by giving them at least a quarter turn every year, or one-eighth of a turn every six months.

SEATING AND KEYING OF RAILS.

The key is a wedge which holds the rails to gauge and checks the tendency to creep. It must, therefore, be kept tight. The common oak or teak keys are inserted by hand from the side of the chair nearest to approaching traffic, the thin end (usually marked with an "S") being inserted. They are then driven tight with the thick end of a keying hammer. To conserve energy one should only grip the handle firmly enough to direct it; with a good swing the hammer will do its own work.

If it is necessary to hold the rail up to the inner jaw to insert the key (as, for example, when a new rail has been put in), a second man holds a bar upright between the rail and the outer jaw and pulls it towards the four-foot way, taking care not to stand with his head immediately in line with the bar, as it may slip or be knocked out of the chair. As mentioned under "Lifting", slack sleepers should be held up to the rail by means of a bar placed under their ends while the keys are being driven.

To drive out a key the thin end of the hammer is used. It is dangerous to strike one hammer against another for this purpose. If a key has to be chipped out with the point of a bar one should take care not to have one's foot near to it, in case the bar hits the chair or rail and glances off.

If keys shrink they must either be replaced or packings must be inserted behind them.

Steel keys are of various types. Some are driven with a keying hammer like wooden keys, but others are inserted by hand and then expanded by driving in an internal wedge with a hand hammer. Steel keys should not be driven out by a direct blow of the hammer, but with a key drift. In some cases hammers lighter than normal are used for steel keys to reduce the risk of overdriving which might break the chair or key.

CARE OF JOINTS.

The defects which can occur at rail-joints are :—

(1) Slack sleepers.
(2) " Pumping " of formation.
(3) Wear of fishplates and rails at fishing angles.
(4) Battering of rail-ends.
(5) Broken fishplates.

These defects usually occur roughly in the order given, but usually they are interdependent, and the development of one defect, if allowed to proceed unchecked, rapidly leads to the growth of others. It is, therefore, very necessary that fish-bolts should be kept tight but not so tight as to prevent expansion and contraction of the rails, and that the joint sleepers should be kept firmly packed. The " running-on " sleeper tends to get down more rapidly than that under the " running-off " end, owing to the blow of the wheels running on to another rail, but it is not wise to pack this sleeper *high* on this account, as to do so would put an undue load on the fishplates immediately before a wheel passed over the joint.

The hatched area on Fig. 9 shows the manner in which wear of the fishplate takes place, this wear being greatest in the centre of the top of the fishplates and least at the ends. As the wear proceeds the joint becomes less rigid and the blow as each wheel strikes the running-on rail becomes the more harmful. This wear can be taken up by the use of liners or shims, the ordinary liner being a thin strip of metal inserted between the fishing surfaces and the shim a liner specially shaped as shown in Fig. 13. The advantage of the shim is that it gives a much greater bearing surface than the liner, being shaped to the actual form of the worn fishplate. Shims are available with various thicknesses at the centre, and care must be taken to avoid using one which is thicker than the wear, as the result would be either a high joint or a broken fishplate. To fit a liner or shim the plates should first be removed and the nib which may have formed on the plate between rail-ends chiselled or ground off. Liners or shims are not generally used at insulated joints ; it is better to provide new plates.

Wear of fishing tables is minimised by keeping the joint sleepers packed and by annual oiling of the fishplates. The oiling permits the free expansion and contraction of the rails, and should be done in the early Spring, as the time of greatest movement is usually in April or May, when the range of temperature between night and day is greatest. The annual oiling of plates has the advantage of ensuring that the fishbolt nuts do not become rustbound and also gives an opportunity for examining the rail ends for fractures, the webs being cleaned with paraffin for this examination. It is usual to change the position of the fishplates at each oiling in order to get longer life from them, standard fishplates being normally turned end for end (not upside down) and refixed on the opposite side of the same rail, though the practice varies on some Railways.

On some districts it is the practice to turn the fishbolts end for end when the plates are oiled in order that the Inspector may quickly verify that the oiling has been completed.

Insulated fishplates must not be oiled.

Fishbolts which have become rustbound should have paraffin applied to them first and then, the next day thin oil.

Fishplates may be broken in two ways :—

(1) If the crack appears on the underside it suggests that the joint sleepers are too far apart and/or *both* slack.

(2) If the crack appears on the upper side (as it usually does), it suggests that one of the joint sleepers is very slack.

Fishbolts should be kept just to that degree of tightness to which a man of average strength can turn them with the spanner provided for the purpose. The use of piping to give greater leverage will result in the stripping of the threads.

RAIL CREEP.

Most rails over which traffic moves have a tendency to move gradually in the direction of the dominant traffic. The reason for this " creep ", as it is called, is not fully understood, but it is believed to be due to the " ironing-out " of a yielding track by a moving load, augmented by braking loads and by the impact of the wheels on the running-on ends of rails, particularly at times when they are seeking to expand or contract. In order to check the tendency of rails to move forward in the chairs, keys, except the ones immediately ahead of a fishplate, are driven in the direction of traffic so that any creep will wedge them more tightly. If the inner rail of a sharp curve shows a tendency to creep backwards

owing to the effect of the fixed axles, it is sometimes the practice to drive some of the keys of that rail against traffic. This practice is sometimes necessary on very sharp upward gradients. Various forms of rail anchors have been devised ; they are usually designed to be clipped to the rail so as to bear against a sleeper or chair. Where " supported joints " are used, the fishplates may be of L-section, the horizontal leg or table being spiked to the sleeper. While these devices assist very materially, they are not entirely effective as the sleepers may be thrust forward, particularly on the cess side, where the ballast has a lower resistance. In time the sleeper may be pushed out of square, the cess side leading. With steel sleepers the six foot side may lead. The sleeper most liable to be thrust forward and out of square is that immediately ahead of the fishplate of a " suspended " or standard joint.

In point and crossing work creep is not so prevalent, owing to the better anchorage. It is usually found that the rail-joints open out for some distance beyond a mass of point and crossing work and close up in front of the next mass.

When he finds that from 3 to 5 joints have closed up owing to creep it is time for a Ganger to pull back the rails.

He should take careful measurements of the expansion gaps as existing and choose the length to be dealt with in one operation. (The total amount of gap in the length should be equal to the total amount which should exist on that length). Work should start at the running-on end of the length, commonly just beyond some point and crossing work. The line is then blocked, the keys knocked out and the fish-plates removed or eased. A correct expansion bit is dropped in the running-on end and the rail is pulled back with bars. If the fishplates are removed, the bars can pull against a tommy-bar thrust through a bolt hole. Next the rail is keyed up, the bolts of the joint corrected tightened up, and the expansion bit moved to the next joint, whereupon the process is repeated. It is important that pulling back of rails should be done in cool weather. March and September are probably the best times.

An adjuster which may be used for correcting creep is made by the Hydraulic Engineering Co. It is set at the centre of the length, with the wide joints behind it and the tight joints ahead of it. Expansion bits are put in all the wide joints, all keys on that side are removed and fishbolts loosened. The adjuster then closes up the rails behind it by pushing, leaving a gap of some inches between the rail ends opposite the machine. The corrected rails are then keyed up. The machine is next attached to the rail ahead of it, keys being

removed from that rail and those beyond it, and the fishbolts loosened. These rails are then pulled until only the normal expansion gap is left opposite the machine. The operation leaves some of the gaps wide, and it is then necessary to fix the machine farther ahead in order to close them up to normal by pushing against expansion bits. The last joint sleeper in each length may be left keyed up so as to draw the chaired sleeper clear of the fishplate, the ballast behind it being cleared to allow it to be drawn back.

With this machine one may expect to pull back $\frac{1}{4}''$ mile of track in 4 hours occupation, with 14 men (including Ganger, Handsignalman and Lookout Man).

When correcting creep it is as well to have two spare rails handy, in case it is necessary to cut closures. Such an eventuality may arise from (1) faulty planning of the present job, (2) incorrect allowance for expansion when the road was first laid in or (3) bodily movement of the point and crossing work at the end of the Section.

BUCKLING OF TRACK.

If, owing to creep or other causes, a number of successive rail-joints have closed up, or if the joints are rusted up, there is a possibility that the track may be distorted or "buckled" in hot weather. If buckling occurs or appears imminent, the fishbolts should be slightly loosened and the track should be slued to a slight curve or to an S-bend (or, if there is already a bend, it should be slued outwards). In sluing double line, the six-foot way should be first widened and then, if necessary, the other track may be pulled over to give a normal six-foot again. Clearances to structures and signals should be carefully verified and then, if none of the rails or joints are crippled by the buckling, traffic may be permitted to pass at a much reduced speed.

Any buckling should be reported to the Permanent Way Inspector and any temporary reduction of clearances to the nearest Station Master. After the heat of the day the track should be returned to its correct position and steps should be taken to correct the joints if necessary. Buckling may be caused by insufficient ballast being provided at the sleeper ends and if this is the case, extra ballast should be put down.

MAINTENANCE OF SWITCHES.

In making his length examination, a Ganger or Patrolman should try all hand worked switches, and he should arrange with the Signalman for switches operated from a Signal frame to be moved over at some time when traffic will not be impeded by so doing. If a switch-blade is found not to be fitting

properly against the stock-rail, the defect may be adjusted by turning the union between the first stretcher bar and the point rodding, or the stretcher bars may have been bent and need straightening. The signal Lineman should be informed at the first opportunity and a test made by both men together.

A bent switch-blade may be straightened with a jim-crow, great caution being observed to avoid breaking it.

If a train has run " through " a pair of switches (*i.e.* in the trailing direction with the points set for the other road), the stretcher bars may be bent and the switch-blade may be chipped. The old type of stretcher, a round rod, may be straightened by putting sluing bars underneath it and lifting (assuming that it has bent downwards, as they usually do). The new type, a flat bar should be taken off and hammered flat, in a fire if necessary.

In examining switches of the old type, attention should be given to the cotters and pins with which the stretcher rods are secured to the switch-blades as the fastenings are apt to work out or rust away.

The working of switches may be impeded by sand, coal or other foreign bodies resting on the slide clairs and these chairs should, therefore, be kept clean. A broken stock-rail bolt, too, may fall out and prevent the switch from closing properly, and attention should be given to these bolts at frequent intervals. Before putting one's hand between the stock-rail and switch one should place a key temporarily in the gap to prevent the points being closed.

The gauge should be verified at switches systematically at least once a week.

The portion of the slide chairs on which the switch rail slides must be oiled frequently, and in large stations this work may fully occupy one man who should be protected by a Lookout man when doing it. When the slide chairs are being oiled it is an advantage to brush a little oil on the gauge face of the outside switch rail of the turnout. This reduces the wear on the switch rail in a similar manner to the oiling of the high rail of a curve.

During a snow storm snow falling on the slide chairs may freeze, and so prevent the switches being worked. To prevent this happening salt should be sprinkled on the slide chairs during periods of snow fall, after brushing off any snow already on the chairs, as it has the effect of lowering the freezing temperature of water, and, therefore snow falling on chairs so treated will melt. A supply of salt is generally kept at each Station, or by the Ganger, and the work of freeing points that are blocked by snow, and the sprinkling of the salt is done by the Permanent Way staff.

MAINTENANCE OF CROSSINGS.

Gauging of crossings should be undertaken methodically at least once a week. It is not enough to verify the 4′ 8½″ gauge between running edges; the distance of 4′ 6¾″ from the running edges of the point and splice rails to the edge of the appropriate check-rail should also be verified, or the 1¾″ flangeway measured, for if the check-rail is worn or slack a wheel flange may strike the crossing. If this distance is found to be wrong and the 4′ 8½″ gauge correct, a new check-rail will be required unless the defect can be traced to faulty seating of the existing check-rail, faulty chairs, or loose keys.

If a bright spot is seen on a crossing nose it indicates that something is striking the crossing, and the cause must be sought. Usually it will be found that the check-rail is at fault, but sometimes, under the pressure of creep, the distance between the knuckle and the end of the point rail may have closed up to less than the correct distance of 2½″ x angle of crossing. This distance should, therefore, be measured at frequent intervals. Where creep is prevalent there is a tendency for the bolts which pass through the rail-webs and crossing chairs to be sheared or bent, and this would be noticed when testing them for loose nuts.

The through-bolt passing through the 3″ extension of the bottom flange of the Vee point rail in British Standard material is particularly liable to become loose. In the older types of material the crossing usually tends to work loose and to rattle on the point-chair until, by galling, it becomes low. This defect may be patched up by inserting liners under the point-rail pending the changing of the crossing.

In recent years the reconditioning of crossings by electric or oxy-acetylene welding has been widely applied. This consists of depositing fresh metal on the worn nose and wing rails and by this means, the life of the crossing may be considerably increased. Before the welding of a crossing is carried out, all the crossing and chair fastenings must be tightened, and any defective ones renewed, and also the crossing timbers should be firmly packed.

A careful watch must be kept for broken and defective rails in crossings, as a fracture may be obscured by fastenings or blocks and not visible at a casual glance. A break in a rail in a crossing will generally be heard when traffic passes over the crossing. When a broken or defective rail is found in a crossing immediate steps must be taken to protect traffic, and the part changed as quickly as possible.

If the point or splice rail of a crossing becomes defective it is replaced from stock, but the replacement of a broken wing rail is a simple matter and length gangs usually make

replacement wings themselves, the method for B.S. material being as described below.

A suitable length of rail with the right amount of wear to match the rest of the crossing is selected and cut to the exact length of the original wing rail, and fishbolt holes are drilled at one end.

The angle of the existing crossing and the distance from a point opposite the blunt nose to wing rail joint along the rail are measured. This distance is marked on the new rail, measured from the end at which the fishbolt holes are drilled. The distances of any bolt holes in the web of the original wing rail from the fishplate end are also measured (along the wing rail), and corresponding holes are drilled in the new rail.

From the point marked on the new wing which will come opposite the blunt nose, a distance equal to $2\frac{1}{2}''$ multiplied by the angle of the crossing is measured towards the fishplate end, and a punch mark is made on the rail, and from this punch mark a distance equal to 6″ multiplied by the angle of the crossing is also marked in the same direction.

The rail is then heated sufficiently to make it easy to bend with a crow. The centre arm of the crow is then placed against the punch mark and the rail bent until the distance between the last point marked on the rail, and a straight edge placed along the free end of the rail is 6″.

This distance must be checked after the rail has cooled and if it has then altered, the crow must be applied again, until the distance is exactly 6″.

The free end of the wing rail must then be heated and bent so that the distance between it and the straight edge in the same position as above is $1\frac{3}{4}''$.

The method of bending the rail is shewn in Fig. 40.

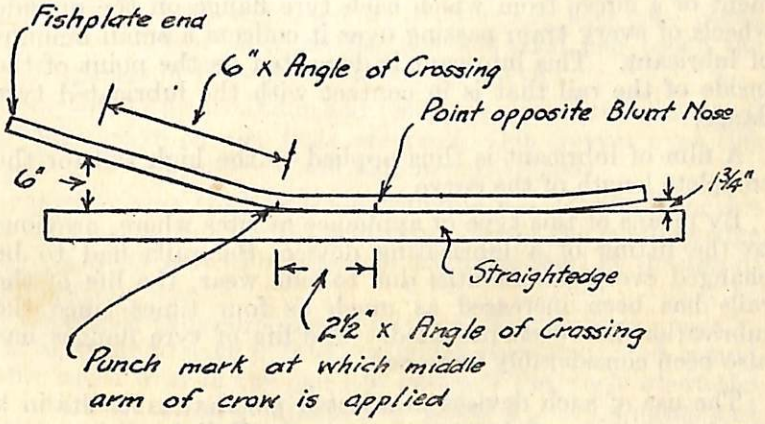


FIG. 40. REPLACEMENT WING RAIL.

When using the crow it is desirable to place a bar between the centre arm of the crow and the rail head, so that it touches the foot of the rail. This helps to prevent the rail being pulled out of upright by the crow.

RAIL LUBRICATION.

As explained in the Chapter on 'Curves' when a vehicle travels round a curve, the outside wheels of the vehicle press against the outside rail of the curve, and it is this pressure that causes the side cutting of the high or outside rail shewn in Fig. 83.

This side cutting may reach such proportions under very heavy traffic that it becomes necessary to change the rail after a few months. At the same time as the rails are being worn, the flanges on the tyres of the wheels also wear, and in the interests of safety tyre flanges cannot be allowed to get below a certain thickness. It will, therefore, be appreciated that the wear due to the pressure between the tyre flanges and the high rails on a curve, is a source of considerable expense to the Chief Mechanical Engineer's Department as well as to the Engineer's Department.

With a view to reducing this wear the problem of providing lubrication between the tyre flanges and rails has been under investigation for some time.

The two methods that have been tried are :—

1. By an appliance on the engine which feeds oil to the flanges. This system has the defect that the oil tends to find its way on to the rail table, which leads to driving wheel slip, and has a bad effect on train braking.

2. By an appliance fixed to the track near the commencement of a curve from which each tyre flange on the outside wheels of every train passing over it collects a small amount of lubricant. This lubricant is deposited on the point of the inside of the rail that is in contact with the lubricated tyre flange.

A film of lubricant is thus applied to the high rail for the complete length of the curve.

By means of this type of appliance at sites where, previous to the fitting of a lubricating device, the rails had to be changed every few months due to side wear, the life of the rails has been increased as much as four times since the lubrication has been provided. The life of tyre flanges has also been considerably increased.

The use of such devices in selected places thus results in a great saving in maintenance costs to the Railway Companies,

and it is the Permanent Way man's duty to see that any such devices fixed on his length are kept in good order so that the best results may be obtained from them.

Lubricating devices fixed to the track are used in this country and they are of two main types as described below :—

1. A device by which lubricant is conveyed to the tyre flanges by means of a felt pad, which is immersed in an oil bath, the oil soaking through the pad from the reservoir. The example of this type is the 'Williams' Rail Oil Box' which will be described later, and its maintenance explained.

2. A mechanical device by which lubricant is forced to the tyre flange by the action of the train passing over it. These devices are of two main types—one in which the deflection of the track under the train actuates pumps which force the lubricant contained in a reservoir to a position from which the tyre flange can collect it, and the other in which the pumps forcing the lubricant to the required position are actuated by the treads of the wheel tyres. The latter type is coming into favour in this country, and a description of the machine of this type manufactured by the 'P. & M' Co. (England) Ltd., and known as the 'P. & M' Positive Feed Rail and Flange Lubricator, is given later, and its maintenance explained.

Williams' Rail Oil Box.

This lubricator, which uses a light machine oil, consists of a metal reservoir for oil, in which a felt pad is partly immersed. The reservoir is attached to a baseplate which is cut at each end to fit against the base of the chair for B.S. 95 lb. rail. The boxes are placed on the straight track about a coach length from the commencement of the curve, between two adjacent sleepers, and fixed to the sleepers with two coach screws, in such a position that the felt pads just touch the running edge of the outside rail of the curve.

For curves up to about 250 yds. in length two boxes fitted in consecutive sleeper beds are used. For curves over this length three boxes are fitted in consecutive beds.

The Williams' Oil Box is illustrated in Fig. 41, and from this it will be seen that the felt pad should cover the running edge of the rail up to within about $\frac{1}{8}$" from the level of the top of the rail.

The pad is thus compressed by every flange passing over it, and in order to save it from too much pressure, which would cause rapid wear of the pad, the gauge of the track where the oil boxes are fitted is widened by about $\frac{1}{4}$", and a check rail fitted to the opposite rail to that on which the boxes are fitted.

The check rail should span at least two sleeper spaces in front of the boxes and one behind. Thus with two oil boxes in the set six check chairs and a check rail at least 16-ft. long are required. With three oil boxes in a set, seven check chairs and at least 18 ft. 6 in. of check rail are needed.

The widening of the gauge must be done on the oil box side, and the running rail on the check rail side maintained in a straight alignment. As the chairs on the check rail side have to be replaced by check chairs, it is better when fitting the check rail to widen the gauge on the check rail side and then slew this side to a straight alignment before the boxes are brought into use.

When oil boxes have to be fitted at the reversal of two curves without any straight between them, the true curvature of the running rail on the check rail side must be maintained.

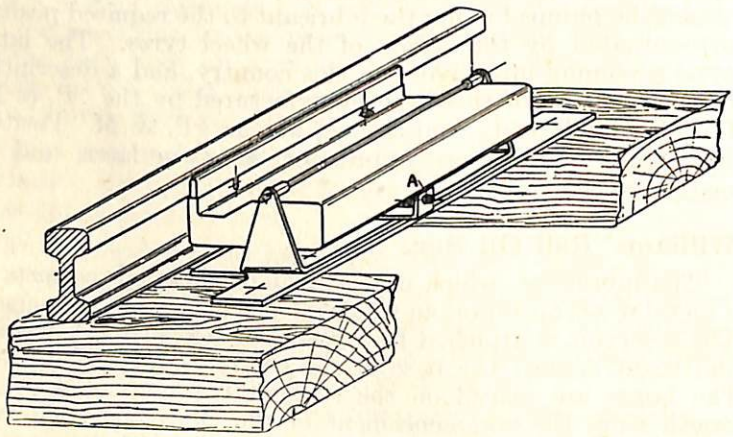


FIG. 41. WILLIAMS' 'ALL ENCLOSED' RAIL OIL BOX.

It is essential in this type of lubricator for the pad to deflect as wheels pass over it, otherwise the life of the pad would be very short. In the earlier type of Williams' Rail Oil Box, the pad was attached to pieces of spring steel, roughly Z shaped, and these springs were in turn attached to the reservoir. A metal lid was fixed to these boxes, but even so, rain water found its way into the reservoir, and forced the oil out on to the ballast. This waste can now be avoided by fitting an attachment known as an "Overflow Pipe." An improved box, known as the 'Williams' All Enclosed Rail Oil Box', has been introduced and provided these boxes are not misused, no oil is wasted due to rain water getting into the reservoir, and there are no springs attached to the pad.

This is the type of Williams' Rail Oil Box shewn in Fig. 41. These boxes give very good results when well maintained, and the main points to be given attention are as follows :—

1. The pad must be kept in a position so that the top of the pad is $\frac{1}{8}''$ below the top of the rail. The height of the pad can be adjusted by means of the nuts on the screwed rod under the reservoir. Tightening the nuts lowers the pad, and slackening the nuts raises the pad. When adjusting the nuts the one nearest the plate must be adjusted first, the other tightened against it, and the first nut then screwed back half a turn. This locks the two nuts in position.

2. The pads must be cleaned every day, otherwise they will be come hard and the oil will be unable to seep through. They should be scraped with a piece of wood or metal by the Ganger or Patrolman when patrolling the length.

3. The pads should be reversed every week or fortnight, according to the density of the traffic. The pads should be taken out and the edge that has been run over put in the reservoir, and the edge that has been in oil is then run over for a period. The pads should not be left too long before reversal, as when this is done the pad becomes burred over and it is then difficult to reverse the pad. If the pad does become burred it should be trimmed with a knife ; the jaws of the container must never be prised open to take a worn pad. The life of the pads varies between about six months and a year depending on the density of the traffic.

4. The spiral spring under the reservoir should be renewed when it becomes weak as it is liable to do under heavy traffic.

5. If an overflow pipe is fitted, this should be turned to one side after rain, when any water in the box will run out, the oil remaining in the box. The normal position of the pipe is with the outlet pointing straight upwards.

'P & M' Rail and Flange Lubricator.

This lubricator uses a graphite grease which gives good results in reducing side wear. The standard type of lubricator consists essentially of a lubricant container, in which the grease is under the pressure of a spring and a piston, and which is fixed on the outside of the rail to be lubricated, two pumps which are attached to each end of the lubricant container casting and fit against the back of the rail, and a greasing plate assembly.

The greasing plate assembly consists of three plates, a front plate, a greasing plate which has fourteen grooves on one side, and which fits against the running edge of the rail, and a back plate which fits against the web of the rail. The

whole is held in position by two hollow bolts which pass through the greasing plate assembly, through $1\frac{1}{8}''$ holes in the web of the rail, and are screwed into tapped holes in the lubricant container casting. The greasing plates are held together by three bolts.

The height of the pumps can be adjusted so that the top of the plunger may be between the limits of $\frac{1}{8}''$ below, and $\frac{3}{8}''$ above the top of the rail. The usual position is $\frac{1}{8}''$ above the top of the rail, in which position the plungers are depressed by passing wheels, and so grease is forced through ports to the hollow bolts, through which it passes to the greasing plate assembly where it is collected by the wheel flanges.

The greasing plate can also be adjusted for height, the usual position being for the top of the plate to be $\frac{5}{8}''$ below the top of the rail. The most satisfactory height for the pumps and greasing plate must be found by experiment at each site.

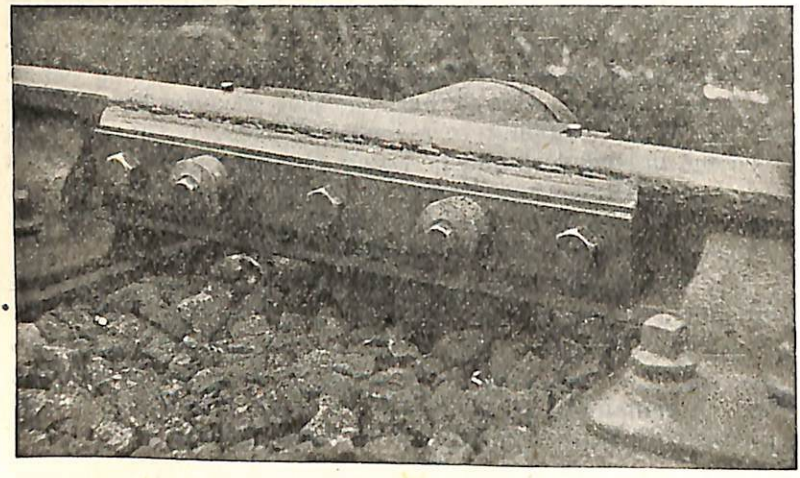


FIG. 42. 'P & M' RAIL AND FLANGE LUBRICATOR.

A 'P. & M.' Lubricator for steam operated lines is shewn in Fig. 42.

For use on electrified lines, where, on account of the conductor rail, the container cannot be fitted outside the running rail, a modified type of lubricator is supplied. In this the container is fitted in the four-foot, and the container casting extends under the rail, the pumps being attached to this on the outside of the rail.

The maintenance of these machines is as follows :—

1. The container should be refilled when a rule can be inserted 5″ into the hole in the container cover. This may be

done either by removing the cover and filling by hand, or by the use of the funnel and filler hole provided on some models. In the latter case a screwed handle is passed through the hole in the cover and screwed into the piston. Screwing this handle further then draws the piston back, and sucks grease in through the funnel. Care must be taken to see that the bottom of the funnel is completely filled with grease otherwise air will be drawn in.

2. The pump plunger and greasing plate must be maintained in the required positions.

3. All bolts must be kept tight by the spanners provided, but care must be taken not to strain the bolts. The spanners must not be lengthened in any way.

If the machine fails to deliver grease it may be due to—

1. An air lock in the container.

2. Dust or other obstruction in the plunger guide hole in the pump casting.

3. Worn or defective washers in the pumps.

4. Dust or grit in the interior of the pumps.

5. Leaks which may arise due to the machine not having been correctly installed or maintained.

For the methods of dealing with these troubles, and for a fuller description of the appliances, reference should be made to the booklet issued by the ' P. & M.' Co., concerning these lubricators.

CHECK RAIL LUBRICATION.

Where excessive squeaking occurs when vehicles traverse a curve which is checked, this is usually due to the intense rubbing of the backs of the wheels against the check rail. The noise is objectionable in a residential area, and it may generally be eliminated by fitting a ' Williams' Check Rail Oil Box ', made by the same firm as the ordinary rail oil box previously described. This consists of a sorbo rubber pad covered with felt, which is half immersed in an oil bath. A pair of check rail oil boxes is fitted in consecutive beds about a coach length before the check rail starts. The backs of the wheel flanges press lightly against the pad and collect a small amount of oil, transferring it along the check rail.

The sorbo pad and felt should be reversed regularly, the part which was in the oil being placed uppermost. This prolongs the life of the pad and felt.

The oil bath is open and therefore it is impossible to keep rain out of the reservoir, and an overflow pipe, as described previously for Rail Oil Boxes, should be fitted to every Check Rail Oil Box.

TRACK ON WAY BEAMS ON BRIDGES.

On many bridges and viaducts and at engine pits and coal drops it is not practicable to use the cross sleeper type of track. In such cases it is usual to lay longitudinal timbers, often called way beams, to which chairs are secured in the usual way, the gauge between the rails being maintained in most cases by placing timber transoms between the way beams notched or housed into them. Steel tie bolts are placed alongside the transoms and through the way beams to prevent spread of gauge, being held by nuts on the outside. These nuts can be kept tight by the use of a spanner. To provide superelevation on track carried on way beams, it is usual to use a heavier way beam to carry the high rail, the amount of cant being maintained by the increased thickness, or height, of the high rail way beam over the lower but to maintain the inclination of the rails at 1 in 20 the tops of the timbers should be cut, or set, to tne same rake as sleepers would have, were the track sleepered. A straightedge should be placed across both timbers to ensure this.

With flat bottom rails on straight track, the inclination of the rails at 1 in 20 is maintained by the top surfaces of the way beams being cut to that amount when sawn.

Way beams on bridges are often held to the steelwork by iron straps and bolts, and these must be kept tight.

Except in cases in which it is desirable to have a trial assembly in the depot, the usual practice is to fix the timbers on the bridge or other structure without chairs or other Permanent Way material affixed to them. The chairs are then carried on and one rail lined up and screwed down, the other rail being afterwards set out from it with a gauge.

If correctly set out in the first instance, tracks laid on way beams do not readily develop serious faults in top or line. If a kink does develop, it should first be ascertained that any wedges with which the timbers may be secured are tight. Next the chairs on the affected length should be unscrewed, the screw-holes filled with wooden plugs, or 'Philplug' compound, and the chairs screwed down in their correct positions. A low point may be lifted by inserting thin fibre packings between the chairs and the timbers, or the use of two-level chairs, but if the need for such lifting arises it is as well to test the timbers with a pricker for internal decay.

The gauge of tracks on way beams should be checked frequently.

Occasionally way beams project over the ends of a bridge and their ends are supported on the ballast. It is essential in these cases to see that the parts of the way beam on the ballast are firmly packed.

TRACK CIRCUITS.

It is frequently necessary for a Signalman to have an indication in his Box to shew whether or not a section of track is occupied by a train or vehicle, and this is generally arranged by providing a ' track circuit ' to the section of track.

This consists essentially of connecting a supply of electric current to the rails at one end of the section, and a device called a ' relay ' to the rails at the other end of the section. The section of track is ' insulated ' electrically from the track on either side by providing insulated joints as described on p. 24 at each end of the section.

The current passes the full length of one rail between insulated joints, through the relay, and back through the full length of the other insulated rail.

The current is generally obtained from an electric battery, but it may be obtained from a power supply, through a suitable reducing transformer.

The effect of a train or vehicle entering the section is to short circuit the relay; *i.e.* the current, instead of passing through the relay, passes from one rail to the other through the wheels and axles of the train, and the relay, being robbed of current, is de-energised.

Certain signal levers and block instruments are so controlled or ' locked ' that they are free to be used by the Signalman only while current is passing through the relay, *i.e.*, while the track circuit is unoccupied or ' clear ', and an indicator in the signal box shews the Signalman whether the section is ' clear ' or ' occupied '.

Any piece of metal, such as a bar or a steel tape, placed across the four foot of a track circuited section so as to touch both rails will cause a short circuit and de-energise the relay, and mislead the Signalman into thinking the section is occupied when it is not, and also prevent him operating the levers or block instrument to accept a train on or across the line which is track circuited.

This is a simple example of locking, but in a busy station this locking may be very intricate, and the accidental short circuiting of a track circuit may cause serious delays to traffic.

For this reason care must be exercised when using metal objects on track circuited lines, and when testing the 4′ 8½″ gauge, an insulated, or wooden, gauge must be used.

Any object short circuiting a track circuit should be removed immediately, and the Signalman advised of the occurrence.

Care must be taken to see that no object lying on the ballast touches the rails, and that the ballast itself is clear of the rails

and chairs, as this would lead to a leakage of current from one rail to the other through the earth, especially in wet weather, and so reduce the efficiency of the track circuit.

To provide a path of less resistance to current than the normal joint affords, bond wires are fixed to connect together the rails on each side of each joint within the track circuited length, and these should be kept clear of the ballast or any object lying on the ballast.

The insulated joints must be inspected periodically to see that the insulation is in good order. Whenever an insulated joint is dismantled, a representative of the Signal Department should be present.

CONDUCTOR RAILS.

For electric traction it is essential to have a *positive* conductor from which the current is supplied to the trains, and a *negative* conductor to which it returns after passing through the motors.* There are three principal ways in which these two conductors may be arranged :—

(i). Positive conductor wire overhead ; track rails serve as negative conductors (*e.g.*, L.N.E.R. Manchester-Sheffield and London-Sheffield, M.S.J. & A.R., L.M. & S.R. Lancaster-Heysham, and most light railways).

(ii). Positive conductor rails supported on sleeper-ends ; track rails as negative conductors (*e.g.* Southern Railway, L.N.E.R. Newcastle, L.M.S. Liverpool-Southport and Manchester-Bury).

(iii). Positive conductor rail supported on sleeper-ends ; negative return rail in centre of four-foot way (*e.g.* Mersey Railway and L.P.T.B., with their prolongations over G.W.R., L.M.S. and L.N.E.R. lines).

The usual position of the positive conductor rail is outside the four-foot way, the distance from and height relative to the running rail varying on different Railways. The positive conductor rail may be set on either side of the track, whichever may be the more convenient having regard to the position of junctions, platforms, etc., there being collecting shoes on both sides of the trains. The conductor rail is supported on insulators fixed on the sleeper ends at about every fifth sleeper, the insulators being attached to the sleepers by iron clips secured to the timbers with coach screws. The conductor rail rests on top of the insulators, in clips which allow a certain amount of longitudinal movement. Various types of anchors are provided to check creep.

*This statement is adequate as a practical explanation, although it is not entirely scientific.

The principal features of the maintenance of conductor rails are :—

(i). The clips at the base of the insulators must be kept tight to prevent vibration.

(ii). The insulators must be kept clean to prevent leakage of current.

(iii). The conductor rail must be kept up to its correct height by adding wooden packings as required to prevent loss of contact and consequent burning away of the rail head.

(iv). The fishplates and bolts must be oiled frequently and loosened in hot weather, as the conductors have very little anchorage against buckling.

(v). The conductor rails must be pulled back after creep, to which they are particularly prone.

At the ends of sections of conductor rail, ramps are provided to pick up the shoe. The effect of creep is to force the end of the ramp forward into a position where it may become foul of a converging track or of a level crossing and care must be taken not to allow the rail to creep so far. If allowed to proceed unchecked, creep may also result in damage to the bonds between rail-ends by their being dragged through insulator clips, or in the tearing off of feeder cable connections. Where side ramps are provided to pick up the shoes of a train which has passed through a turnout, creep would have the effect of making the side ramps wide or tight to gauge.

Laminated or stranded copper bonds are provided to transmit current across the joints in the conductor rails. In the pressed or riveted type of bond connection to the rails, the bond ends are fitted with terminals which are forced into a clean hole in the rail by a hydraulic press. When the bond connection is a welded one the bond terminal is welded to the bottom table of the conductor rail, the bond strands being underneath the rail and lying in the same plane. If the strands of a bond become broken, the bond must be replaced, as arcing across the joint would result from the failure of a bond.

Where the return current is passed through the running rails, copper bonds are provided at the joints, and at crossings to distribute the return current quickly. Across ordinary joints they may be fixed underneath the fishplates, the terminals being forced into holes in the webs between the fishbolt holes by a ' pin-press ', worked by two men, the fishplates being fixed afterwards. Other types pass outside

the fishplates, giving space enough for tightening the fish-bolts. Short bonds, oxy-acetylene welded to the rail head, are now extensively used and result in a considerable economy in copper. Longer bonds are necessary to connect a wing rail to a crossing, or an angle wing to an angle point rail. They are also required to provide cross connection with the return rail where such a rail exists ; elsewhere bonds may be provided across the six-foot to get better distribution at points where trains use a great deal of current in accelerating.

Ballast and other materials must not be placed near the conductor rail, and on the side of the track where there is no conductor rail, they must be kept clear of the idle collecting shoes of the trains, which may be only about an inch above rail level.

It is advisable to use a gauge to verify that the path of idle shoes is clear through point and crossing work, for the requisite distance from the running face each side of every track, particularly when the rails of the main line are worn low and those of a crossover road or siding are still of full height.

PRECAUTIONS ON ELECTRIFIED LINES.

In this book references are made under the appropriate headings to the additional precautions to be adopted on electrified lines when doing certain work on the Permanent Way (*e.g.* Renewal). In this section, therefore, it only remains to deal with certain general aspects of work near live rails. Detailed instructions are issued by each Company regarding procedure in emergencies and/or when the current is cut off for engineering work, and these notes do not in any way supersede such instructions.

A ' short circuit ' takes place when the electric current is able to pass directly from the positive conductor to earth or to the negative conductor, without taking its normal course through the motors. A short circuit occurs when a metallic object (or any wet object) touches the live rail and the track or return rails at the same time. A flash results, and the current is then automatically cut off at the sub-station by the circuit-breakers ; it cannot be restored until the offending object has been removed. Apart from the damage to electrical equipment and the interruption of the train service which may result from the short circuit, there is the danger that the flash may injure or blind a man or at least make him inattentive to approaching trains.

Electric shock occurs when the current passes through a man in passing from the live rail to earth, to the track, or to

other negative conductor. This may occur through his touching both the live rail and the track rail simultaneously, or, if the ground is at all damp, through his touching the live rail whilst standing on the ground. " Touching " in this case does not only refer to the hands, but includes a tool held in the hands, a damp overcoat, a watchchain or a stream of water thrown from a bucket. If the conductor rail must be touched or if tools must be used near to it, one must wear rubber gloves and/or stand on a rubber mat, and the tools should be covered with insulating material where possible. Gloves which are wet to the wrists or mats which are wet to the edges are useless. If one has to lean over the live rail it should be covered with a rubber mat.

When the current has been cut off for engineering work, a clip or bar is placed across the positive and negative conductors so that if, through a misunderstanding, it were switched on again there would immediately be a short circuit. Unless such a device is known to be in position, one should always assume that the rail is " live ". In a grave emergency, when the current must be cut off at once, a bar may be thrown so as to fall across both rails, but the person throwing it must be prepared for the flash. Whenever anything goes wrong, the sub-station Attendant should be notified by telephone.

Fires near the live rails or feeder cables should be extinguished with sand or dry earth, *not* with water.

CLEANING OF BALLAST.

It is essential that the formation should be kept well drained, and the ballast must therefore remain clean enough to let water pass freely through it. It cannot do this if it is choked up with powdered stone, clay from the formation, sweepings or the roots of weeds. It is usual to riddle the top ballast about every four or five years to get rid of dirt, dust and weeds. The portion of ballast so dealt with is that lying between the sleepers to a depth of about five inches below them ; the beds themselves are not touched except that under the last six inches of the sleeper ends the ballast is loosened. The procedure is to loosen the ballast in question with a pick and then to start at one end by taking out all the ballast from one bay and putting the clean ballast into a barrow ; the next bay is then riddled, the clean ballast therefrom being put into the first bay, that from the third bay is put in the second and so on until the last bay is filled from the barrow. The riddling may be done by a hand-riddle shaken by one man over the cess while another shovels dirty ballast into it, or a

mechanically vibrating riddle may be used. Alternatively, all the ballast in a bay may be dug out with shovels and heaped into the cess, whence it is put back into the same bay with ballast forks, the dirt being left behind in the cess. In any case, the dirt should afterwards be shovelled up, as a gradual raising of the cess would prevent water from getting away from the formation.

If, after cleaning, the ballast is found to be inadequate to fill up the bays, it may be made good by a fresh supply brought to the site by hand barrow or by trolley.

In some cases, however, it may be that the bottom ballast is choked up and that although the water percolates downwards through the top ballast it is held up in pools on the formation or on the bottom ballast. This condition is sometimes partly remediable by giving the bays as opened out for riddling a fall towards the cess, but the only real cure is to take up the track and to dig out all the ballast down to the formation and to riddle or wash it or replace it with new ballast. If the formation is troublesome, the opportunity should be taken to lower it and to increase the cross-fall. The whole of the clean ballast may then be put back and punned or rolled level before the track is relaid.

MAINTENANCE OF DRAINS.

The efficient upkeep of permanent way drainage is essential to good maintenance of the track. If water is allowed to stand in the drains it will in time seep through the half open joints of the pipes and soften the formation, which will lead to trouble with the track going down under traffic.

In most soils, water entering a drain carries with it a certain amount of silt, and, if the drain does not happen to have a good fall, this silt may collect in the pipes and obstruct the flow of water. For this reason all drains should be " rodded " occasionally. This consists of pushing a block of wood roughly the size of the pipes, through the pipes. The block is fixed to a rod with a screwed end, and further rods are screwed on this end to form one long rod. Manholes, or catchpits usually about 100-ft. apart, are provided to enable this to be done.

The floors of manholes are usually built about 6″ below the invert of the lowest pipe in the wall of the manhole, and this forms a sump which catches any silt or foreign matter which has entered one section of the drain, and prevents it travelling right through the whole length of the drain. These manhole sumps must be cleaned out before the silt reaches the level of the outlet pipe in the manhole.

The hardcore or beach filling to the trench in which the drain is laid may become silted up, especially in clay soil, and this will prevent water entering the pipes. If this does occur the filling should be cleaned in a similar manner to track ballast, or if necessary, renewed.

Occasionally a drain pipe may become broken, and this may allow the filling to fall in and perhaps block the drain. This is a serious state of affairs, as all the water flowing into the drain will seep into the formation by the blocked pipe.

If it is impossible to push the drain rods through one section of the drain, the probable cause is a broken pipe. By measuring the lengths of the rods that have been inserted it is possible to fix the approximate position of the breakage, and the drain should be opened up by excavating down to the drain. If a broken pipe is found it must be replaced quickly.

Permanent Way drains frequently discharge into streams or ponds outside the railway property, and any diversion of a stream, or filling in of a pond, which may block the outlet of any railway drainage should be at once reported to the Permanent Way Inspector.

If a slip occurs in soil through which a drain runs, the level of the drain may be disturbed. If the disturbance is serious water may be prevented from flowing through the drain, and the drain trench should be opened up and any irregularities in the gradient of the drain removed, by relaying the drain to suitable levels.

SLIPS.

Causes.

On page 7 are given the angles of repose of various materials. For every material the angle varies according to the moisture content ; it is most stable when merely moist, less stable when quite dry and may be exceedingly unstable when thoroughly wet. Thus a slope which stands up satisfactorily under normal conditions may after very wet weather prove to be steeper than the angle of repose and a slip will then result.

The way in which the water penetrates the less permeable soils such as clay is through the cracks which form during dry weather. Once started, such cracks tend to travel downwards, forming a " plane of cleavage " along which the clay is lubricated by slurry. (A frequent source of these planes of cleavage is the intercepting ditch sometimes found along the top of the slope of a cutting). Robbed of the cohesive force which normally holds clay together, the portion

in front of the crack starts to move, and the plane of cleavage develops underneath the sliding mass, which slips forward until it finds equilibrium by the rising of the toe and the subsidence of the upper part of the affected material. The usual form of a large slip after it has come to rest is shewn on Fig. 43.

If a cutting passes through strata which dip in a direction at right angles to the railway and the strata include a band of shale, clay or rocky material, there will always be a tendency for the material above that band to slide over it, for, being almost impermeable, it will have its upper surface lubricated by the water which has percolated through the overlying material and is following the dip-slope downwards.

Slips in embankments may develop in a similar manner to those in cuttings, the detached mass sliding outwards over a plane of cleavage until it finds equilibrium by the rising of the toe. Of a different nature is the " slumping " of heavy embankments newly formed upon soft ground ; the ground below flows outwards and rises at the toe of the slopes, allowing the heavy core of the embankment to settle. The situation is then made worse by the ponding back of water at the toe, which further softens the ground.

If it is required to ascertain whether a bank is starting to slip, pegs may be driven in a straight line across the area believed to be affected. If they get out of line, movement is taking place.

Prevention.

As slips are almost always due to the saturation of the slopes with water, the essential preventive is good drainage. The construction of slope drains to catch surface water and water from the top surface of an impermeable layer has already been referred to on page 14. It is usually much safer to bring the water quickly to the face and to get rid of it in this way than to hold it up by digging a ditch at the top of the slope ; unless such ditches have a good fall they may be worse than useless. However, as indicated above, there may be danger in having water permeating over the top surface of a bed of clay or shale, particularly if there is a sharp dip in the strata towards the railway. There is, indeed, always danger in having much water in the portion of the ground near to the cutting and above formation. The solution in really difficult ground, therefore, is to construct dry stone counterforts in deep trenches, starting from a raking bearing under the cess and running, at right angles to the railway, far enough into the adjoining ground to intercept

water before it reaches the zone liable to slipping, as shewn in Fig. 43. The counterforts may be about 50 ft. apart, but in bad cases may be 15 ft.-20 ft. apart, and may taper on plan away from the toe. They serve a double purpose; firstly they are struts, against which the earth wedges and holds firm; secondly they form drains to keep dry the portion of earth liable to movement. To fulfil the second function more effectively they may have an open-jointed stoneware pipe drain in the base of each. The longitudinal drain in the cess should be deep enough to drain the lowest part of the foundation of the counterforts. The type of counterfort shewn in Fig. 43 is constructed in a series of steps.

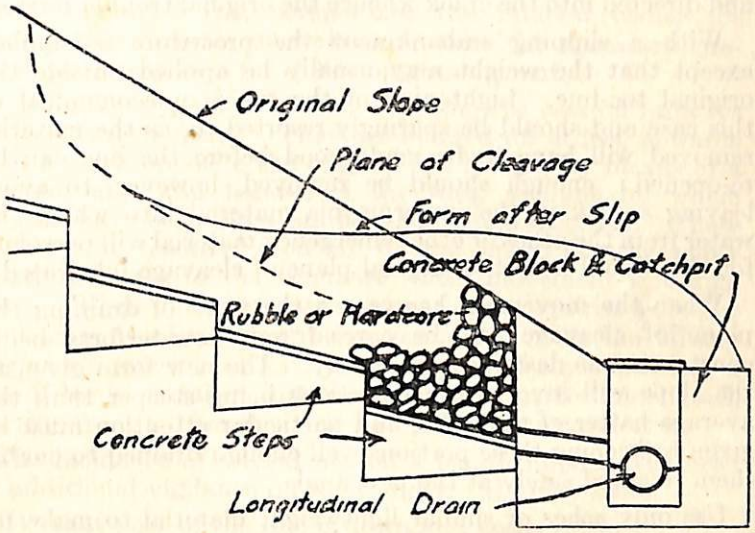


FIG. 43. COUNTERFORT.

The precautions to be adopted against slumping of new embankments are the digging of parallel ditches, well clear of the toe, some time before the bank is formed. Such ditches must, of course, have an outlet, and a good fall. Under-drainage of the site by agricultural tile drains is sometimes recommended; such drains should have a good fall when laid, as the natural ground, under the centre of an embankment will be depressed.

A band of shale dipping sharply across a rock cutting presents a serious problem. The superincumbent rock may be supported by flying arches from the opposite face, or an attempt may be made to drain the plane of cleavage some distance away from the cutting (up the dip-slope) by driving a heading.

Treatment.

In the preceding paragraphs and in Fig. 43 it has been pointed out that a slip stops when it reaches equilibrium. The conditions of this equilibrium give the clue to the treatment of a mass which is on the move. To restore its balance it must be loaded at the toe and lightened at the top. In a cutting the position of the toe is fixed by the clearance from the railway, so a heavy mass of dry stone must be built up from this line, as steeply as it will stand with safety. Behind this may be loaded earth taken from the top of the moving mass. This process must not be carried on to the extent of making the top of the slip level, lest water be ponded back and directed into the crack whence the original trouble started.

With a slipping embankment the procedure is similar, except that the weight may usually be applied outside the original toe-line. Lightening of the top is uneconomical in this case and should be sparingly resorted to, as the material removed will have to be made good before the line can be re-opened; enough should be removed, however, to avoid leaving a nick in the impermeable material into which the water from the ashes or other emergency material will percolate for this would keep the original plane of cleavage lubricated.

When the movement has ceased the work of draining the plane of cleavage can be carried out, counterforts being constructed as described previously. The new form given to the slope will involve some portions being steeper than the average batter of the slope, and particular attention must be given to keeping these portions well enough drained to enable them to stand safely at the new angle.

Use only ashes or similar lightweight material to make up level on a subsiding embankment.

MINING SUBSIDENCE.

When minerals are worked from under the railway, settlement ensues as the props decay and the workings cave in during a period lasting about 5 years after the finish of the working. The amount of settlement averages about 60% of the thickness of the seam directly over the workings, while around the margins of the area of direct settlement there is partial subsidence accompanied by a horizontal "draw" towards the centre of the area. As it is necessary to maintain a uniform gradient on railways the local hollows resulting from subsidence must be taken out by lifting the line and packing additional ballast under the sleepers. (As the consumption of ballast for such purposes is very great, it is usual to make cinder ballast the standard for all lines in districts liable to subsidence).

Bridges and other structures are cracked as the workings pass under or near them, but the cracks sometimes tend to close after the workings have passed. Arches are seriously affected by the uneven settlement of their supports, and may fail unless centering is erected immediately or before the movement starts.

Colliery Companies are under a statutory obligation to serve a notice on the owners of railways and canals before getting the coal from under the works, or from under a strip on either side of them whose width is half the depth of the seam or 40 yards, whichever is the greater. On receipt of such intimation the owners of the railway or canal may either "buy support" (*i.e.* compensate the mineral owner for leaving the minerals unworked) or take the necessary precautions in readiness for the coming movement.

"Subsidence posts" are erected along the cess on railways subject to settlement. They are marked off in feet upwards from a mark opposite the original rail level. By means of a straight edge and hand-level the total amount by which the rails have been lifted can be read off and recorded. These readings are recorded monthly by the length Ganger whose report indicates to the Engineer where movement is taking place. When more accurate information is required as to the total amount of movement for comparison with the Mining Engineer's report and for the assessment of compensation, a line of levels is taken instrumentally by the technical staff, starting from a "bench-mark" outside the unstable area.

The incidence of subsidence on a length imposes the need for additional vigilance on the Ganger. He may see—

(1) that part of the line is down and needs lifting;
(2) that the track has been pulled out of line by the "draw", which occurs when the direction of travel of the workings is across the track, and needs sluing back; and/or
(3) that the expansion gaps between the rails are closed at one point and unusually wide at another, showing that the rails must be pulled back. (The tendency is for the rails to creep towards the centre of the subsidence).

General speed restrictions are sometimes imposed while subsidence is active; in addition, it is often necessary to put Handsignalmen out to slacken trains while lifting is in progress.

ROCK AND CHALK CUTTINGS.

Many types of rock which are quite firm when first exposed are liable to soften or to become friable and flake away when exposed to the weather. Shale and fireclay are examples of

such rocks. Others, such as sandstones and limestones, may contain vertical fissures in addition to their bedding planes, and the effect of exposure to frost is for pieces of rock to be thrust out by the wedge action of ice forming in the fissures, as water expands as it freezes. Where beds of a friable material like shale alternate with a fissured rock, the effect of weathering is to undermine the beds of sandstone, from which loose blocks then fall. This danger is accentuated when the beds dip towards the exposed face.

Examinations must be made of the faces of rock cuttings at intervals, particular attention being given after periods of frost. Any loose blocks which may be found would be a source of danger to trains and should be detached and removed by bars and the like, the men using the tools being secured by ropes from the top of the cutting. When this work is being done, the line should be blocked between trains. The dislodged material should then be loaded up, together with any shale which has accumulated on the cess.

In some cases it is worth while to wall up the soft material in masonry or brickwork to support the overhanging rocks, weep holes being provided in the walls where necessary.

The effect of frosty weather on chalk cuttings is similar to that described above, and the same measures as for rock cuttings must be taken as required.

MAINTENANCE OF LEVEL CROSSINGS.

The roadway over a level crossing may be of timber or ballast, or it may be made up road surfaced with stone sets, tar-macadam, concrete, or similar materials.

All track rails at every level crossing, and foot crossing, whatever the type of road over it, should be fitted with check rails, generally with a flangeway of 2″, to provide a clear pathway for the wheels of trains. It is essential that the check flangeway should be kept clear from dirt and obstruction, otherwise there is a possibility of a train being derailed.

Timber paved level crossings are often used where it may be necessary to take up the surface frequently, such as temporary level crossings, and on quays and jetties in harbour works. The timber paving is usually screwed to blocks of wood fixed to the sleepers and these fastenings must be kept tight. Small coach screws are usually used for the fastenings and it is a simple matter to remove any defective timber that requires renewal.

Ballast is generally used for the paving of farm or occupation crossings, and for foot crossings. It should be kept free from

weeds, and the top of the ballast must be kept up to rail level, as otherwise farm vehicles may not be able to get across, or pedestrians may trip over the rails.

The surface of paved roads over level crossings should receive attention periodically, and if any ' pot-holes ' or loose patches develop, they should be patched with suitable material, or if necessary the whole crossing resurfaced.

If an accident occurred to a member of the public using a level crossing, through a defect in the surface, a claim for damages may be brought against the Railway Company, and, therefore, should any serious irregularity in the surface be discovered, the matter should be reported to the Permanent Way Inspector immediately.

When a level crossing is being laid down, it must be borne in mind that any repairs required to the track over it, when the crossing is completed, will entail the roadway being taken up again, which, besides being expensive, may cause inconvenience and delay to the users of the crossing.

It is advisable, therefore, whenever a crossing is opened up, to inspect carefully all the components of the track, renewing those that appear worn or decayed, and thoroughly tightening all fastenings and packing all sleepers. If a rail joint occurs on a level crossing, an effort should be made to move it off the crossing, on account of the difficulty of keeping a good top. This may be done by laying in a longer rail, or by cutting the two rails on one side of crossing and pulling back the next full rails to the cuts. This will leave a gap to be filled by the pieces cut off.

If it is not possible to move the joint, short fishbolts are used, and the fishbolt nuts are placed on the inside of the track, in the check flangeway. A special thin spanner may be used for tightening these nuts.

At a level crossing on an electrified line, provision must be made in the surfacing for the clearance of the current collecting shoes of electric stock. It is necessary that for the width thus required no part of the surfacing shall be above the plane of the rail tops. This should be checked by placing a straightedge across the rails, when it should either just touch the road surface, or be above it for the required distance outside the gauge face of each rail.

At all crossings, level and foot, certain notice and warning boards are erected for the guidance of the public using the crossings. The Ganger should ensure that these are readily visible to the users of the crossing, and are not obscured by new buildings, trees, hedges or other obstruction.

At certain farm occupation crossings, the Farmer is under an obligation to keep the gates to the crossing locked when not in use. Any breach of this obligation should be reported by the Ganger to his Inspector.

If the Ganger becomes aware that the land on one side of an occupation crossing has passed into the ownership of a different person from that of the land on the other, he should report the matter, as in these circumstances it may be possible to remove the crossing.

MAINTENANCE OF ROADS AND FOOTPATHS.

Occasionally the repair of roads and footpaths on Railway property is carried out by a Contractor, or in the case of roads over bridges, is done by the Local Authorities who charge the Company a certain sum per annum for each bridge.

Generally however, for small roads and footpaths the repairs where not too large are carried out periodically by the Permanent Way Staff.

The only maintenance required is the keeping clear of weeds, and the patching of small defects in the surface. It is better to do this patching when the defect is small than to allow it to develop into a large pothole which might cause an accident to any person, or damage to vehicles.

Tar paving should preferably be done in warm weather as the tar will then penetrate the surface more easily, and also coat the stones more completely.

WEEDING AND CHEMICAL WEED KILLING.

Weeds on the Permanent Way, in addition to being unsightly, also cause the ballast to become choked with dirt, so preventing water falling on the track from running away, which leads in time to the decay of the components of the track.

The only way to prevent weeds growing in the track is to keep the ballast clean. Weeds will not grow in clean stone ballast, though there are some types which will grow through it when their roots are established in the formation underneath.

Where weeds are growing on the track it is necessary to remove them, or in the case of long rooted weeds, to check their growth.

This should be done in the early Summer before the seeds fall, and sow another year's crop of weeds.

This work is generally done by the Lengthmen who, equipped with hoes, devote a certain period of the year to

going right through the length and uprooting or chopping off all weeds in the track, and cesses, but the work is expensive and laborious.

In order to relieve the Lengthman of this job and free for more profitable work, chemical weed killing is being increasingly adopted. The usual method of applying chemical weed killer to the track is by means of a special train of tanks fitted with nozzles which spray the chemical, diluted with water, over the track.

The advantages of this method, are that long lengths of track can be treated in a short time, and that chemical weed killer is a certain destroyer of practically all weeds, whereas by the old hand weeding, the weeds were generally chopped off, and the roots left to grow again later.

For use in small Goods Yards and Sidings, where it is not possible or economical to take the weed killing train, on cable routes, and on Approach Roads and Platforms, chemical weed killer is supplied mixed with sand, in tins fitted with sprinkler tops for application by hand.

The chemical generally used in this country is a mixture of Sodium Chlorate, and Calcium Chloride, which is non-poisonous and non-combustible.

GRASS CUTTING.

During February or the first half of March, advantage should be taken of any dry spell to burn off all dead grass and weeds on the railway banks. Small areas should be burned at a time, in order that the fire may not get out of control, and the clearing of long grass from fences and hedge bottoms should precede the burning, in order that no damage may result. The man doing the "torching" should have his shovel with him to beat out the flames if necessary. Care should be taken to avoid nuisance to persons living near the railway, and endangering adjoining property by the fire spreading or by flying sparks.

After the torching, any loose debris or big stones which might damage the scythes during the later operation of grass-cutting should be removed. The grass cutting should be done in June or July, according to locality, before the grass begins to seed, to check the spread of seeds to the top ballast and cesses. It should be done with a scythe, or, in confined spaces, with a reaping hook. On some Railways a 'swath' is cut at the top and bottom of a grass slope and the standing grass between swathes is then burnt. On a slope the scythe is usually swung below the Operator. Near signal wires the

hook is used, the wires being held aside with a stick, not with the hand. If two men are using scythes at the same time, they should work well apart.

When the cut grass is dry it may either be burned where it lies or gathered up and sold. In some cases arrangements are made with local Farmers to cut and remove the grass; any offers to do this received by a Ganger should be passed to his Inspector.

FENCES AND HEDGES.

The principal types of fence used for keeping animals and trespassers off the railway are :—

(1) Hedges or quick fences.
(2) Timber post and rail fences.
(3) Timber post and wire fences.
(4) Concrete post and wire fences.
(5) Wrought iron post and wire fences.
(6) Unclimbable iron fences.
(7) Wire mesh fences.
(8) Rubble stone walls.
(9) Brick walls.

Hedges are usually set out at a certain distance, which varies between 3 ft. and 6 ft. in different localities, inside the railway boundary, in order that when cutting them the Lengthmen may remain on railway property. They should be trimmed about the end of September, when the sap is falling, the object of trimming being to keep each plant bushy by cutting off the main shoots at a height of about four feet, and at about a foot on each side of the centre line. The work is done with a hedging knife, with a quick slashing motion, the hands being protected by leather gloves, treated with tallow to give a good grip of the knife handle. Cutting with shears is usually only resorted to where the appearance of the lineside is of considerable importance.

Weeds and long grass should be cleared away from the foot of hedges and fences in order to check the risk of their catching fire, as explained on p. 133. Advantage may be taken of any period when men cannot work on the tracks to dig 'fire borders' alongside hedges and fences. On some Railways these fire borders are dug by machine.

This precaution also diminishes the decay which attacks timber posts near ground level. For the same reasons the base of timber mile-posts, gradient-posts, telegraph posts and similar uprights should be kept clear. On some Railways the ground around them is dug over and sometimes covered with chippings.

Fence-posts or rails weakened by decay or fire or damaged by live-stock should be replaced as soon as possible. In the usual type of timber fence (which is made from old sleepers) the rails are scarfed at each post, and a rail is changed by loosening one post at its base.

Wire fencing needs to be tightened up at intervals, especially in hot weather, and the straining gear should be oiled annually.

TREES.

In addition to general vigilance throughout the year, an annual inspection of trees near the track is necessary. Any tree which is leaning towards the track or which appears to present any potential danger to the track in the event of a storm should be reported. Arrangements can then be made for it to be made safe. In making such an inspection it should be borne in mind that Elm trees have the peculiarity of suddenly dropping branches which appear quite healthy; any Elm branch which, if it should fall, would endanger the railway should be reported.

Yew or other poisonous trees growing on the Company's property, but spreading far enough for animals to reach them, should be lopped.

DERAILMENTS.

Serious derailments to passenger trains are fortunately comparatively rare occurrences, and the duties of the permanent way staff in regard to these are usually confined to rescue and repair work under the direction of an Engineer.

Minor derailments, however, generally in shunting operations, are more frequent and this section is devoted to the duties of the lengthman when these occur.

If the derailment takes place and the derailed vehicle fouls a running line the first essential is to protect traffic in accordance with the rules, and to report the matter immediately to the Permanent Way Inspector, Station Master, Signalman, or other person or persons required by regulations. In any case if any signalling apparatus is damaged, the nearest Signal Department Staff should be advised as quickly as possible, and they should be given as accurate a description of the damage as possible, in order that no time be lost in effecting the repairs.

If the work of rerailing the derailed vehicle is obviously too heavy for the strength of the local gang the Inspector should be advised immediately, and requested to arrange for a breakdown train and crane to be provided.

If, however, the job of rerailing can be done by the local permanent way staff this should be done as quickly as possible in order to reduce traffic delays to a minimum.

Jacks and bars may be used for this, and in some cases it is possible to draw the vehicle on to the rails, again, using re-railing ramps or improvised skids, particularly if only one pair of wheels is derailed. Care must be taken in using jacks to see that they are placed under a part of the vehicle which is strong enough to take the weight, and it may be necessary to unload the vehicle before attempting to rerail it.

When the vehicle is rerailed the ganger must carefully inspect the track, and, if it is damaged to such an extent that it is unsafe for traffic, or that a speed restriction is necessary, he must take the appropriate steps to ensure the safety of traffic in accordance with the Rules.

Damage may be caused to chairs, keys, sleepers, switch tongues, stretcher bars, crossings, and signal fittings. As far as possible, the repairs should be put in hand at once. A careful note should be made of all damage for insertion in the report which the Ganger must send to his Inspector.

In this report the following information is generally required :—

(1) A description of the mishap with the date, time, and site of the occurrence, the time when the vehicle was rerailed, and details of delays, if any, to traffic.

(2) Details of the type of vehicle.

(3) The names of the train crew, persons in charge of shunting operations, and signalmen where applicable.

(4) Details of any injuries to persons.

(5) The names of any witnesses.

(6) The cause of the derailment, and any other relevant information.

(7) A sketch of the site of the derailment.

The causes of derailments are often difficult to find, as, in cases of doubt, the staff of any Department are naturally loth to take the blame.

Derailments generally cause much inconvenience and delay and, it is essential that the causes should be accurately ascertained in order that they may be removed and so help to prevent repetition.

Unless the cause of a derailment is obvious, as would, for instance, be the case were a rail broken, or any obstruction left on the rails, or unless a member of the staff admits

responsibility, it is usual for a Joint Enquiry to be held by representatives of all Departments concerned. At these enquiries staff connected with the occurrence, and the permanent way ganger, are required to give evidence so that the cause of the derailment can be ascertained.

Derailments may be caused by any of the following :—

(1) Mistakes made by the traffic staff, as for instance, when switches are moved whilst a train is passing over them, when a misunderstanding occurs between signalmen, shunters and engine crew, or when stock is roughly shunted.

(2) Defects in the rolling stock, such as broken wheels, tyres, or engine connecting rods.

(3) Uneven loading of a vehicle, which may cause a twist in the underframe of a vehicle and so lead to a wheel climbing on to the top table of the rail.

(4) An obstruction, either on the rails, in the check flangeway, or on slide chairs at switches which may prevent these closing properly.

(5) A train may be brought to rest on a rising gradient on which safety (or catch) points are provided, and due to slack couplings or other cause, a vehicle may run back sufficiently to be derailed at these points.

(6) Defects in the permanent way.

With regard to the last item, the ganger must make a careful inspection of the track at the site of every derailment, even though to a casual glance it may appear in good order. Particular attention should be paid to the following :—

(*a*) Switches—these should be tested to see that they work properly, and that the signal fittings are satisfactory.

(*b*) Crossings—all fastenings must be tested for tightness.

(*c*) Gauge—the gauge of the track must be checked especially in point and crossing work. The gauge of check rails must also be looked into especially at crossings.

(*d*) Cross level—this must be checked at close intervals as a sudden reversal of superelevation will set up rolling of stock which is occasionally the cause of derailments, as may be too much superelevation.

(*e*) Material—the condition of the track components should be carefully examined, special note being made of the condition of the fastenings.

BROKEN RAILS.

Rail breakages may be caused by :—

(1) Faults in the structure of the rail.

(2) Bad maintenance. This applies particularly at joints at which the sleepers are not properly packed.

(3) So many holes having been drilled through the web that the strength of the rail has been reduced too much for the loads it has to carry. This is especially the case at joints where there are of necessity holes in the web of the rail for the fishbolts, and where additional holes may be drilled for various purposes and may not be apparent, owing to the fishplates.

(4) Welding. This applies particularly to crossings that have been reconditioned by welding.

In sidings, breakages are not infrequent, especially in locomotive depots where the axle loads are heavy, and the sulphurous atmosphere causes rapid corrosion of the rails. In running lines, however, they are comparatively rare, due no doubt to the high degree of strength and resilience insisted upon by the Railway Companies for new rails. For this reason where a rail of full section (*i.e.*, not reduced in any way by planing, such as are parts of switches and crossings) breaks in a running road, the rail is usually analysed by a Metallurgist to find out if the cause lies in the manufacture of the rail.

It is found that rail breakages are more frequent in very cold weather than at any other time, and that flat bottomed rails are more liable to break than bull headed rails.

The consequences of a broken rail may be very serious, and it behoves the permanent way staff to keep a continual watch for any signs of cracks and fractures.

The most frequent places at which breaks occur are at joints and crossings. In these places they may not be easily visible as they may be covered by fishplates, or by blocks, and especial attention must be paid to these parts of the track. In the case of a complete fracture at such a place, the sound made by traffic passing over the spot may be distinctive.

On the discovery of a broken rail steps must be taken immediately to protect traffic, either by reducing the speed of trains, or, if necessary, by blocking the line affected, until the part can be changed.

If the break is clean, and no part of the rail head is detached from the web it may be possible to fit a pair of fishplates over the break and to respace the sleepers on each side of the break to give temporary support pending the insertion of a

new rail. If the fracture is not serious and the traffic is light it may be sufficient to put in a support with a chair and key under the break.

These measures are, of course, only temporary expedients and no time must be lost in inserting a new rail.

The occurrence must be reported to the Permanent Way Inspector.

The Inspector is generally required to forward a piece of the rail incorporating the break, together with a report of the circumstances, to the Engineer. If the length of the rail cut off for this purpose is exactly 3′ 0″, the length can be weighed to give the weight per yard, and hence an indication of the amount the rail is worn. A standard form is usually issued for use in these cases on which the Inspector must give such information as the age, type, and, maker's markings of the rail, and details of the site, including the gradient, and curvature, whether the rail was in the Up or Down road, and the estimated number of trains passing over the rail daily. If the break is at a joint it is essential to say whether the broken rail end was on the leading or trailing side of the joint.

A sketch should also accompany the report, and should show the distance of the break from the nearest end of the rail and from the centres of the chair seatings on either side of the break.

BRIDGE EXAMINATION BY LENGTH GANGERS.

A Ganger should go under each underbridge at least once a week to see whether any defects are apparent, and it is as well to go over the overbridges at similar intervals. He is not required to make a detailed examination of the structure, but he should observe and report any development which would appear to menace the safety of the line or of the roads, etc., crossing the line. Some of the defects for which he should be on the lookout are given below.

The abutments, piers or wing walls may be cracked. If old cracks have dated cement pats on them, the cracking of a pat indicates that they are still moving. A crack may appear between a spandril wall and the arch ring, indicating distortion of the arch, or the rings of the arch may separate. If this separation occurs internally, the arch sounds " drummy " or hollow when tapped. Distortion of an arch may show by the rising or falling of the centre of the parapet wall (or of the track, in the case of an underbridge). Such movement may be regarded as a serious defect, particularly if accompanied by cracking of the arch ring or crumbling of mortar on the intrados. Loose bricks or copings should be reported if they

may fall on the line or on a road. The bedstones or impost courses of girder bridges and the skewbacks of metal arches may crack, particularly if they have been long subject to softening by acidulated water running over them, and there may then be a risk that detached portions may fall. Wing walls, spandril walls and, less commonly, abutments, may bulge owing to the earth pressure behind them or they may tend to heel over. Piers, abutments and wing walls of bridges over rivers and streams may be undermined by the current during flooding, and the inverts of culverts may be scoured away, particularly at the downstream end. If there are weep-pipes in a wing wall or abutment and they never discharge any water it may be assumed that they are stopped up, particularly if any pitch can be seen in them. Pitch frequently stops up the weep-pipes or gargoyles which should drain the valleys between arches in a viaduct, to the detriment of the arches and spandrils, and of the line over it. In girder bridges with brick or stone parapets cracks usually appear over the ends of the girders owing to the deflection of the girders, but no ill effects need be feared from such a defect.

The commonest defect in steelwork and ironwork is corrosion (rusting), but this develops so slowly that it may be seen by the Works Inspector or the Painters before it has assumed serious proportions. However, if a Ganger sees such defects developing he should make sure that the Inspector is aware of the fact. If a crack is seen in a girder or if a web is seen to be buckled the fact should be reported at once. If a girder lifts off its bearing and hammers it during the passage of a train it may be regarded as a source of rapid deterioration, and any undue movement of a bridge under load should be reported. Where there are cast iron columns they have a tendency to crack in frosty weather if they have become filled with water. The lugs for attachment of bracing to such columns are sometimes found to be broken off.

Timber floors of bridges, when covered with ballast are particularly subject to rot, which usually begins over the bearings of the timbers. (For maintenance of track on longitudinal timbers see page 118). The principal danger to which timber is subject is that of fire, especially on electrified tracks, and one of the duties of a Ganger is to see that fire buckets are kept filled wherever they may be needed for dealing with fires on bridges. Timber overbridges are often weakened by partial burning of the main beams. The out-riggers of timber footbridges are often burned or decayed enough to allow the parapets to be shaken by hand. Holes may develop in the timber floors of footbridges, to the discomfort and perhaps danger of persons using them. Where

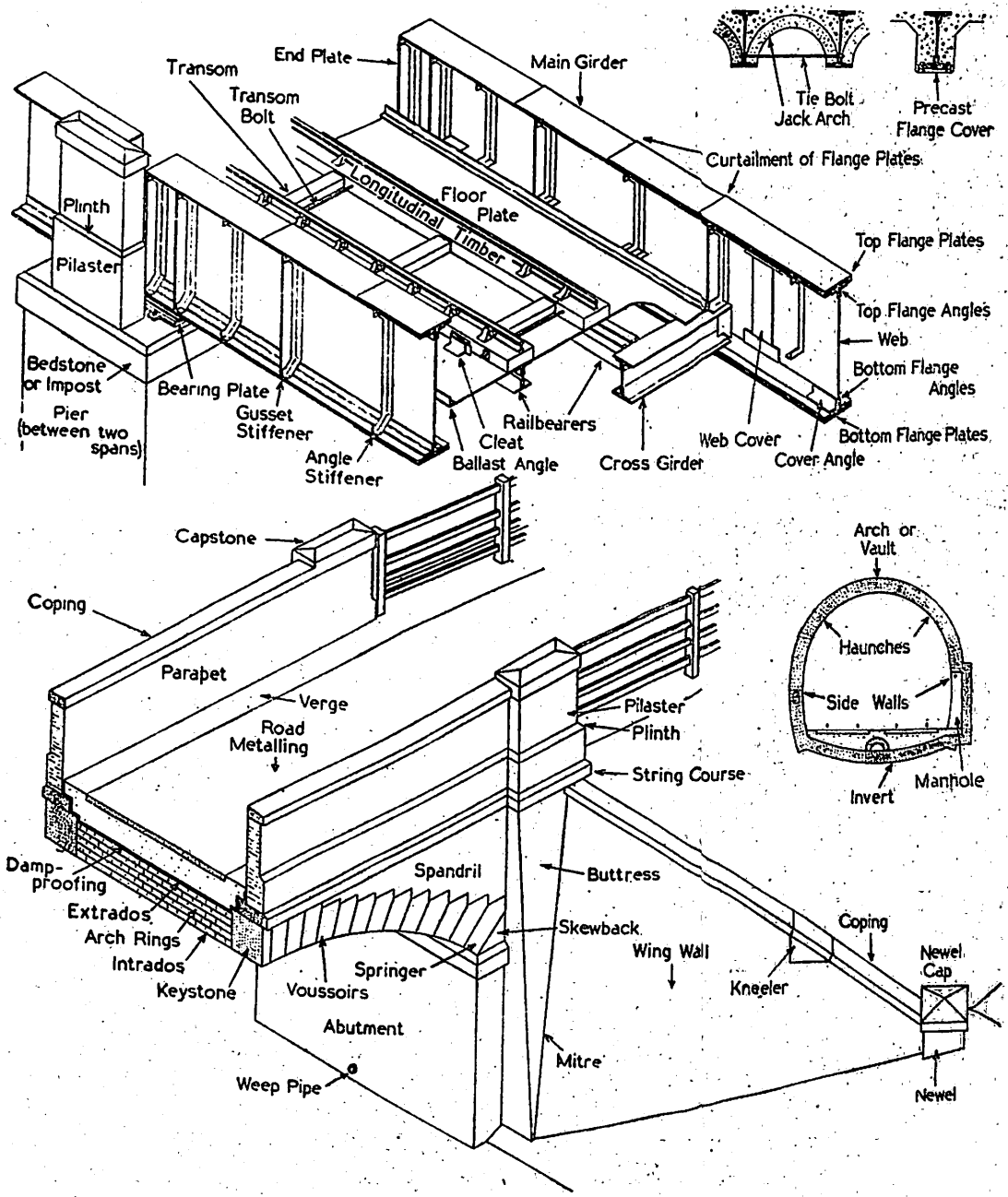


FIG. 44. BRIDGE DETAILS.

timber smoke-troughs are fixed, any fire or decay may loosen the hold of the hook-bolts by which they are attached.

The fencing to both overbridges and underbridges needs attention. Adjoining public roads the fencing must be strong and free from decay, and any space through which children might fall should be closed up. Handrails on underbridges sometimes get loose and may get foul of traffic if not given attention. Splintered or broken handrails on footbridges should be reported.

Rain and other water falling on underbridges should be drained away rapidly in the interests both of the permanent way and of the structure. It should pass to the ends of the bridge and should there flow into channels or chases which lead it away; it should not be allowed to flow down the abutments. For this reason ballast on bridges should be kept clean, accumulation of dirt cleared away and drains kept clear. Ashes and rubbish must be cleared from girder webs and floorplates and from all pockets in the girderwork, as they encourage corrosion. Signal wires and cable trunking on bridges should be kept clear of rubbish, and telegraph wires under public overbridges should be looked at to see whether anything has been thrown upon them.

STRUCTURE CLEARANCES.

For newly constructed railway structures in this country, the Ministry of Transport Regulations stipulate that no structure may be built within certain fixed distances from the rails. The main distances that affect permanent way staff are those to structures at the side of the track, overhead clearances and platform clearances.

When a structure has been built in accordance with the Ministry of Transport requirements the permanent way staff should ensure that the clearances are not reduced in any way by slewing or lifting of the tracks. For this reason when a new structure, such as a bridge, is proposed, it is desirable to investigate the alignment and level of the tracks at the site, and slew and lift the tracks as may be necessary before building is commenced. Alternatively the structure may be built to clearances which will allow such slewing and lifting to be carried out afterwards.

With existing structures, however, the Ministry of Transport standard clearances are frequently not obtainable, and it is usual to work to a minimum clearance, such as 6″, outside the loading gauge for the lines on which the structures are situated. As the loading gauges vary on different routes it follows that there is no uniformity in the clearances from structures to rails.

Most length gangs are provided with a frame for testing the loading gauges at stations and goods yards, and this frame is, therefore, suitable for a structure gauge, since all structures must be 6″ (or other specified clearance) outside the tester.

The minimum clearance outside loading gauge is necessary to allow for, amongst other factors, oscillation of rolling stock at speed. Railway Companies are frequently asked to carry loads which are larger than the loading gauges for the routes over which they have to travel, and this clearance often allows such loads to be accepted, provided the speed is reduced when the load passes structures at which only the minimum clearance exists, since, at low speeds, oscillation is very small.

It is necessary, therefore, that the minimum clearance outside loading gauge be carefully maintained. Owing to the packing of sleepers the level of the rails tends to rise appreciably over a period of time, and for this reason no fettling should be carried out under an overline structure without the gauge being checked to see that the minimum clearance is not encroached upon.

It is a common practice amongst permanent way staff, in fettling, especially where the formation of the track is poor, to pack the track higher than the final level aimed at with the idea that subsequent traffic will depress the track to the desired level. This must not be done so as to encroach on the minimum clearance under any structure as, whilst after the passage of a few trains, the minimum clearance may be restored, it might occur that an out-of-gauge load is one of the first to pass under the structure.

On curved track structure clearances must be increased to allow for the throwover of stock, and adjusted on account of superelevation on the track.

Taking the question of throwover first, for clearances to structures at the side of the track, the allowance to be made can easily be arrived at as shewn in Fig. 45.

Fig. 45 represents the plan of a vehicle on a curved track. A B is the centre line of the track and C D the centre line of the vehicle. E and F are the centres of the outer axles (or bogie centres on bogie stock) and, assuming the wheels to be central in the four foot, it follows that in plan E and F are over the centre line of the track.

It will be seen from the figure that the centre of the vehicle projects towards the inside of the curve by the amount marked ‘ X ’ which is known as the ‘ overthrow ’. Similarly

the ends of the vehicle project towards the outside of the curve by the amounts ' Y ' and ' Y_1', called the ' endthrow '. On account of throwover, side clearance to structures on curved track must exceed the clearances necessary on straight track by the amounts X, Y or Y_1. (The adjustment due to superelevation will be dealt with later). On a curve of constant radius Y and Y_1 will be equal.

Vehicles for which X and Y are equal in amount are called ' balanced '. For ordinary main line curves it is usual to assume X and Y to be equal at any point, although X is often greater than Y, and to determine the value of X only. If Y is then taken to be the same as X the error is on the safe side. There are cases, however, where Y is greater than X and these will be explained later.

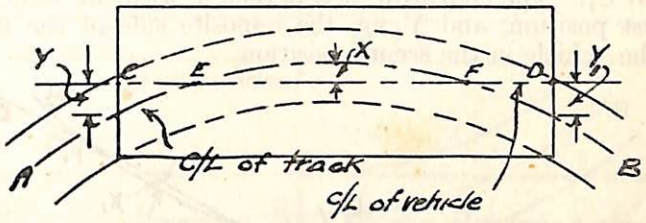


FIG. 45.

Referring to Fig. 45 it will be seen that the distance X is equal to the versine of the curve on a chord length equal to the wheelbase of the vehicle, *i.e.*, distance between the axles, or the distance between bogie centres. The greater the wheelbase, therefore, the greater will be the value of X, and on any route excess clearance on curves must be provided to allow for the overthrow of the longest wheelbase stock using the route.

Generally speaking, bogie stock has a longer wheelbase than any other, and with modern stock the average distance between bogie centres is a little over 40 feet. All that is necessary to find the overthrow on any curve is to determine the versine of the curve on a chord length equal to the longest wheelbase of stock that passes over the curve.

This can either be measured on the ground or, if the radius of the curve is known, calculated from the formula

$$V = \frac{(\frac{1}{2}C)^2}{2R}$$

In the formula C is the wheelbase in feet and if R, the radius of the curve, is measured in feet, V will be the overthrow, also in feet.

It may be noted here that the overthrow on any curve, where a 44 ft. wheelbase is taken as the basis for overthrow calculations, is $\frac{1}{9}$ of the versine of the curve on a 132 ft. chord, or $\frac{4}{9}$ of the versine of the curve on a 66 ft. chord.

There are two main cases in which the endthrow 'Y' is generally greater than the overthrow 'X' with balanced stock. These are at reverse curves and at turnouts.

In Fig. 46 AQ and QB represent the centre lines of two curves reversing at Q.

In Fig. 46A, a vehicle is shewn in two positions CD and C_1D_1 (representing the centre line of the vehicle in each case, E and F being bogie centres). In the first position one end of the vehicle D is shewn opposite the point of reversal of curvature, and in the second the other end of the vehicle is opposite this point at C_1. The endthrow at Q is then Y with the vehicle in the first position, and Y_1 on the opposite side of the track with the vehicle in the second position.

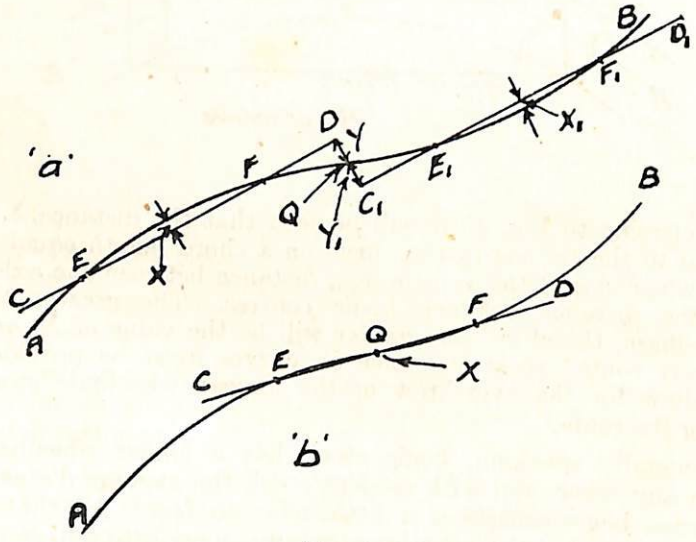


FIG. 46.

If the curves are of equal radii and are directly tangential (*i.e.* no transition curve exists) Y and Y_1 will be the same value, and equal to the overthrow X and X_1 on each curve.

In Fig. 46B, the vehicle is shewn with its centre at the point of reversal of curvature, and it will be seen that the overthrow X is smaller than Y or Y_1 in Fig. 46A. If the curves are of equal radii and directly tangential the overthrow at Q will be zero.

In Fig. 47 is shewn a turnout from a straight main. The centre line of the main and turnout is the line ASB, S being at the switches.

If we imagine a vehicle, centre line C D, bogie centres E and F, travelling along the main from A towards B, when it reaches the position shewn in Fig. 47A, *i.e.*, with the leading bogie centre at the tip of the switches, for all practical purposes the endthrow at C will be zero, *i.e.*, C will be vertically over AS.

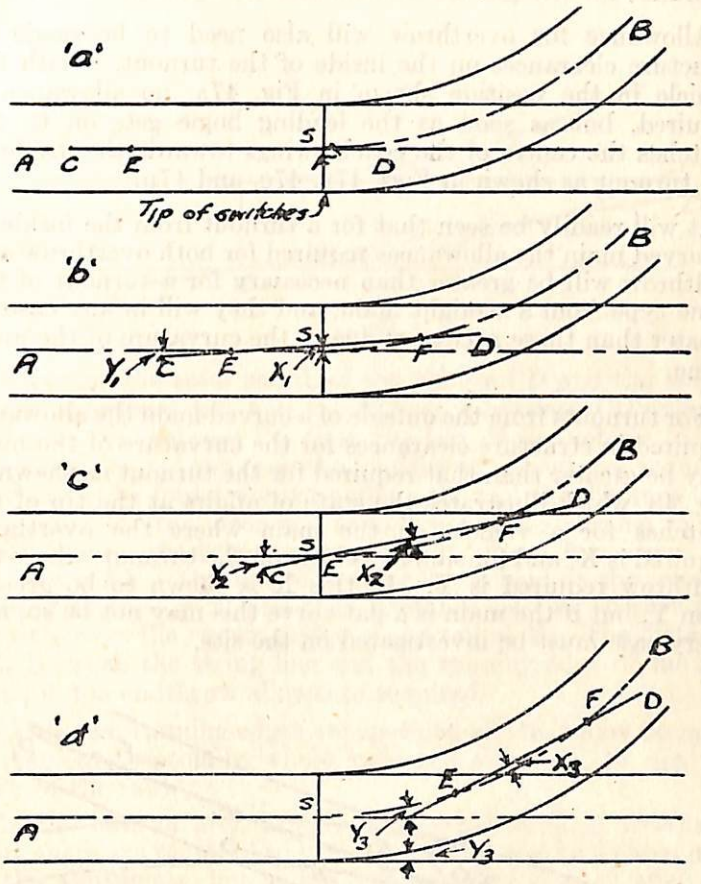


FIG. 47.

As soon as the leading bogie is on the switches the end of the vehicle will begin to swing away from the line AS as shewn in Fig. 47B, and there will be an endthrow Y_1. This allowance required for endthrow will increase from zero in the position

in Fig. 47A until the position in Fig. 47C is reached, *i.e.*, the trailing bogie centre E is over the tips of the switches, when it is generally at its maximum.

As the vehicle passes through the turnout the amount that has to be allowed in structure clearances for endthrow will decrease until the position shewn in Fig. 47D is reached, *i.e.*, the rear end of the vehicle is at a point at which the endthrow of the vehicle on the turnout is equal to the distance between the switch and stock rails. At this point the standard clearance for straight track is all that is required.

Allowance for overthrow will also need to be made to structure clearances on the inside of the turnout. With the vehicle in the position shewn in Fig. 47A, no allowance is required, but as soon as the leading bogie gets on to the switches the centre of the coach swings towards the inside of the turnout as shewn in Figs. 47B, 47C, and 47D.

It will readily be seen that for a turnout from the inside of a curved main the allowances required for both overthrow and endthrow will be greater than necessary for a turnout of the same type from a straight main, and they will in any case be greater than those necessary due to the curvature of the main alone.

For turnouts from the outside of a curved main the allowance required in structure clearances for the curvature of the main may be greater than that required for the turnout as shewn in Fig. 48, which illustrates the state of affairs at the tip of the switches for a vehicle on the main where the overthrow required is X, and for similar vehicle on the turnout, where the endthrow required is Y. In this X is shewn to be greater than Y, but if the main is a flat curve this may not be so, and every case must be investigated on the site.

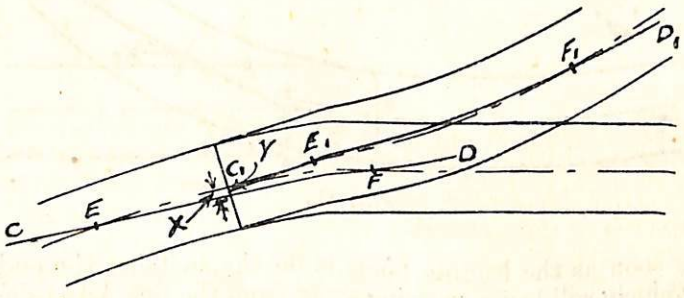


FIG. 48.

The method of measuring the allowance required for endthrow, where this cannot be taken as equal to the overthrow, can be seen from Fig. 49.

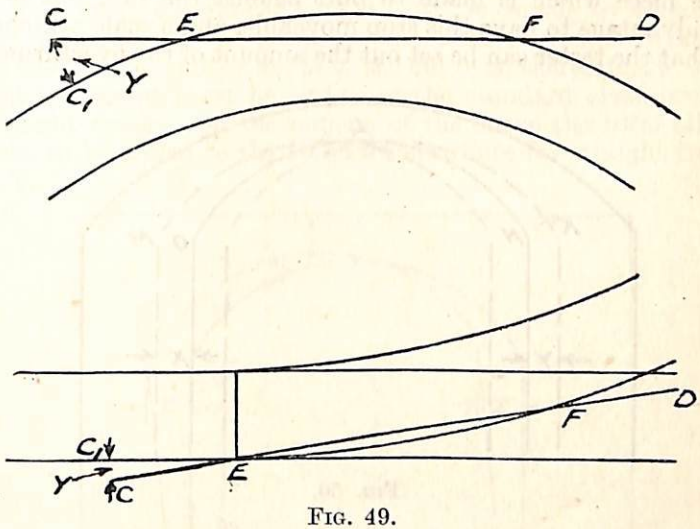


FIG. 49.

Knowing the total length of the vehicle CD and the length of the wheelbase EF, half the difference between CD and EF will give the distance CE from the end of the vehicle to the bogie centre. Assuming the endthrow allowance required at C_1 is to be found, measure along the rail the distance C_1E equal to CE, (the error due to C_1E not being parallel to the centre line of the vehicle is negligible). From E measure the wheelbase EF. One end of a string line is held on the running edge of the rail at F, and then stretched past C_1 so that it is directly over the running edge of the rail at E. The distance CC_1 between the string line and the running edge of the rail at C_1 is the endthrow allowance required.

(Although running edges are specified above it may be more convenient, especially where rails are sideworn, to use the back of the rail).

In the case of arch bridges, the endthrow and overthrow allowances are required to be added to the standard clearances to the abutments, but at the arch ring the state of affairs is as shewn in Fig. 50.

It will be seen that the arch must give the specified clearance to a line KLM, instead of to the line NLO as on a straight track. When a new arch is designed it is a simple matter to arrive at the line KLM on paper, and so determine the necessary dimensions of the arch.

When testing an existing structure, it is necessary to move the tester out so that the arc of the tester occupies the positions KL and LM. Many testers are fitted with a fixed stop on the base piece which is made to butt against the rail, but it is an advantage to have this stop moveable, and a scale attached so that the tester can be set out the amount of the overthrow.

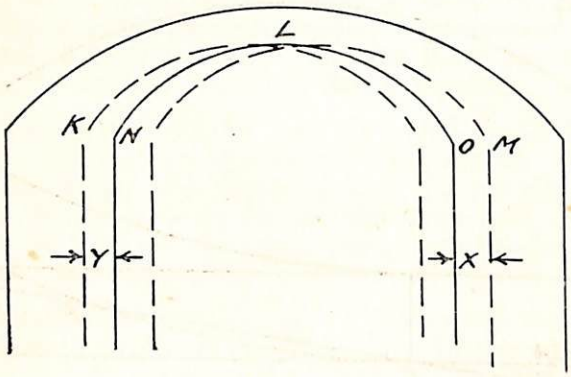


FIG. 50.

The effect of superelevation on structure clearances is shewn in Fig. 51, in which is shewn in full lines a section of a bridge and a vehicle on a track with no superelevation.

Imagine one rail of the track to be raised so that there is a superelevation ' S ' on the track. The vehicle will then take up the position shewn by dotted lines. The cornice of the vehicle is now a distance Z nearer to the abutment on the low rail side, and the same amount further from the abutment on the high rail side.

From the geometry of the figure it can be shewn that Z is very nearly equal to $\frac{H}{G} \times S$, where H is the height of the cornice of the vehicle above rail level, and G is the distance between centres of rail.

In this country H is generally in the region of 11 ft., and G may be taken as 5 ft., whence

$$Z = 2\tfrac{1}{4}\ S \text{ nearly.}$$

For any structure other than a bridge abutment, at the side of the track, of height ' h ' above rail level, the amount of superelevation allowance to be added to clearances on the low rail side, and which in some cases may be subtracted from clearances on the high rail side, is $\frac{h}{G}S$.

From Fig. 51 it may be seen that on the low rail side of the track the standard clearance must be increased by the amount Z, but on the high rail side practically the same clearance is required as when the track is not superelevated.

The total allowance required to be made to structure clearances on curved track on which there is superelevation, on the low rail side or inside of the curve is, therefore, X + Z, which amount must be added to the standard clearance for straight track. On the outside of the curve the total allowance to be added to the standard clearance for straight track, is Y.

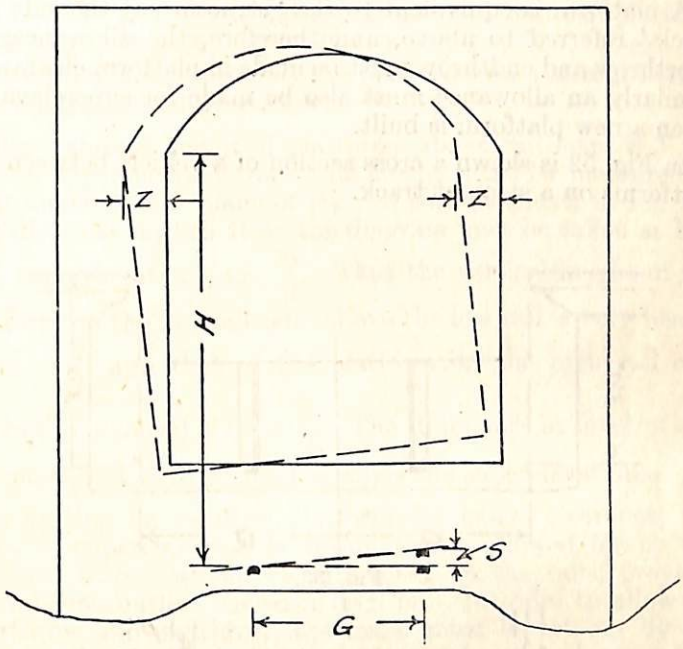


FIG. 51.

The effect of superelevation on clearances to the soffits of arch bridges cannot be calculated exactly, and as in the case of overthrow and endthrow allowances, it is usual for new structures to draw out a cross section of the bridge and track.

In testing existing structures the question of allowance for superelevation does not arise, since the tester, being erected on the rails, naturally produces the dotted outline shewn in Fig. 51.

It may be necessary on occasion to determine whether the superelevation on a curve may be altered at a structure. As the usual method of increasing superelevation is by *raising*

the high rail, and of decreasing superelevation is by *raising* the low rail, all that is required to determine whether any alteration to existing superelevation is possible, is to place packing pieces of the required thickness under the tester on the appropriate rail. If the tester shews that with the amended superelevation the required clearance is not obtained, it may be necessary to lower one of the rails or slew the track. The amount of lowering or slew necessary in the case of an arch bridge can best be determined by making a survey of the arch, and deducing the required amount from a large scale drawing.

A platform is equivalent to the ' structure at the side of a track ' referred to above, and therefore, the allowances for overthrow and endthrow must be made in platform clearances. Similarly an allowance must also be made for superelevation when a new platform is built.

In Fig. 52 is shewn a cross section of a vehicle between two platforms on a straight track.

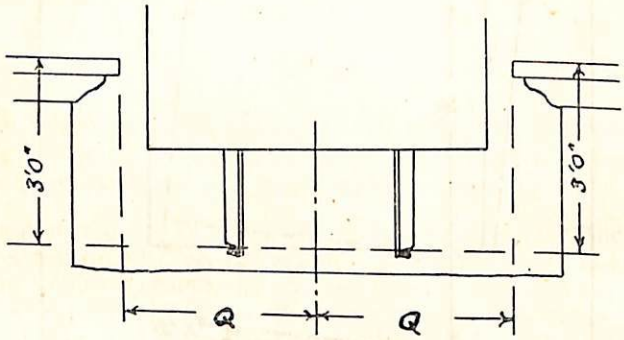


FIG. 52.

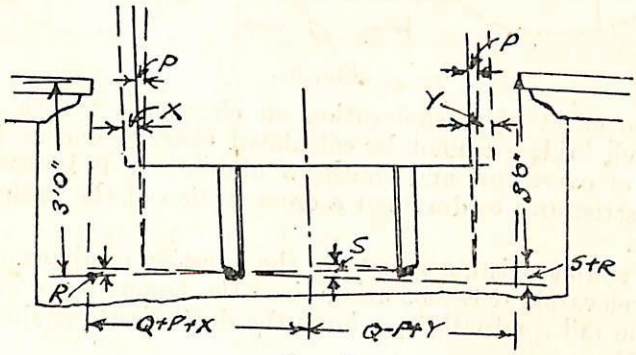


FIG. 53.

Fig. 53 shews a cross section of the same vehicle on superelevated track, the dotted lines parallel to the sides of the

vehicle representing the effect of endthrow and overthrow Y and X. On the low rail the vehicle leans towards the platform by the amount P, and on the high rail side away from the platform the same amount. Taking the distance between centres of rails as 5 ft., it follows that P is very nearly $\frac{3}{5}$ of the superelevation S.

In Fig. 52 the horizontal distance from centre line of track to platform edge is shewn as Q.

From Fig. 53 it will be seen that the horizontal distance from centre line of track to platform edge on the low rail side must be Q + P + X, and to platform edge on the high rail side Q — P + Y. The horizontal distance between platform edges is Q + P + X + Q — P + Y = 2Q + X + Y, *i.e.*, the horizontal distance between the platforms on a straight track plus endthrow and overthrow.

The standard height of platforms above rail level is 3′ 0″, and on superelevated track this height must be measured at right angles to the plane of the rail tops as shewn in Fig. 53. The distance marked R on the diagram may be taken as half the superelevation, *i.e.* $\frac{S}{2}$. Thus the vertical height of the platform on the low rail side, above the low rail is very nearly 3′ 0″ — $\frac{S}{2}$, and that of the platform on the high rail side above the high rail 3′ 0″ + $\frac{S}{2}$. The difference in level of the two platforms is thus equal to twice the superelevation.

In testing an existing platform for gauge clearance, the effect of superelevation is automatically allowed for by the platform tester, which, being erected on the rails, provides the full line outline shewn in Fig. 53. In order to allow for overthrow and endthrow, the tester must be set out by the amount of each as previously explained for arch clearances.

The above treatment of the subject has been confined to a single track, but the same principles apply to any number of tracks, bearing in mind that on the low rail side of any track clearances must be increased by the amount of overthrow plus the appropriate superelevation allowance, and on the high rail side by the endthrow.

TOOLS.

The following are some of the tools in general use by permanent way men :—Hammers, spanners, shovels, forks, beaters, bars, gauges (track, superelevation, and structure), levels, straight edges and blocks (or ‘ cant ladders ’), Abtus

lifting boards and voidmeters, saws, drills, lifting bars, lifting jacks, slewing jacks, jim crows (or rail benders), adzes, axes, rail tongs, sleeper tongs, setts, files, oil cans, lamps, scythes and hedge cutting tools, hoes, lamps, barrows, grindstones, and rubber mats. Saws, drills, and beaters (tie tampers) are occasionally petrol driven, but the maintenance of the engines is usually carried out by a mechanic, or specially trained man.

Time spent on keeping tools clean and in good order is well worth while, as in addition to keeping down the costs for replacements, the permanent way man can do his work better and with less effort with efficient tools.

Tools should be wiped clean and dry after use, and not left lying about by the side of the track. This applies especially to lamps, oil cans, and those tools which have parts of iron or steel. Those with moving parts, such as jacks, rail saws, drills, and rail benders, etc., should have the moving parts oiled frequently.

All tools with a cutting edge, such as adzes, saws, etc., must be kept well sharpened, and in the case of saws it is advisable to protect the teeth with a wooden sheath, thus also guarding against the possibility of accidents to persons.

The wooden shafts of such tools as hammers and beaters should be regularly examined to see that they are in good order and that there is no risk of the head flying off in use, and that there are no splinters on the handle which might cause personal injury.

When using jacks and jim crows, care must be taken to see that they are square to and have a good grip on the rail, and are seated properly. If this is not done the tool may slip and possibly cause injury to the men using it.

For use on electrified tracks the handles of such tools as hammers, spanners, and shovels are bound with insulating material to minimise the risk of men receiving an electric slock should part of the tool accidentally come into contact with the conductor rail. This insulation must not be pressed or knocked against anything which might cut or damage it ; for instance, when using an insulated shovel for opening out ballast, the handle of the shovel must not be levered against the rail. Any tool of which the insulation is damaged should not be used, and steps must be taken to have the insulation repaired as quickly as possible.

When using an alignment gauge, a spirit level should always be used in conjunction with it, as the gauge will not give a true reading unless it is held in a horizontal position. When the centre line of a track is marked by a cut in an alignment

peg, and the track is being slewed to correct alignment, there is a temptation to put one end of the gauge in the cut and slew the track up against the other end. This is a bad practice as there is a risk of breaking the gauge and of disturbing the alignment peg.

Structure gauges and load gauge testers must be stored in a dry place, and should be hung up in such a way that they will not become distorted by their own weight or other cause.

Generally speaking permanent way tools are designed for one purpose only, and they should not be used for any other jobs than the one they were intended to perform. The use of a tool for a different purpose from that which it was designed, may result in the tool being strained. Besides making it less efficient for its correct job, this may lead to the tool breaking at some inopportune moment, and possibly cause injury to the man using it.

As far as possible all tools should be stored in a hut when not in use, but, if this is not practicable, they should be covered by old sacks or similar materials to protect them from the weather.

HANDSIGNALMEN, FOGSIGNALMEN AND LOOKOUTMEN.

The occasions on which a handsignalman must be provided, and the rules which must be adhered to by the person appointing the handsignalman and by the handsignalman himself, are laid down in the Rule Book. All men are required to make themselves familiar with these rules, and it is not, therefore, proposed to deal with the subject in this section.

No man is allowed to act as a handsignalman until he has passed an oral examination in the rules applicable to this work, and he must afterwards be tested periodically in his knowledge of them. It is not sufficient merely to learn the rules off by heart, but each man should endeavour to understand clearly the reason underlying each rule, and he will then be able to deal correctly with any emergency which may arise.

The duties of handsignalmen are very responsible, and men appointed for this work must appreciate that the safety of traffic depends on the rules being strictly carried out.

When a handsignalman is required his duties must be clearly explained to him by the person appointing him, who must also satisfy himself that the necessary flags, lamps, and detonators are in good order.

On arrival at his post the handsignalman must place himself in a position of safety, and from which his signals can be

seen by train crews. He should stand well clear of detonators, as pieces of the metal containers may cause personal injury when the detonators explode.

The handsignalman must not leave his post until he is relieved, or instructed by, or on behalf of, the person who appointed him that his duty is completed.

Handsignalmen should be posted whenever the line is broken, or when there is an obstruction on the line which may be a danger to traffic. Examples of such obstructions are a trolley, a fall of earth in a cutting, a slip, and a traction engine or a heavy agricultural implement crossing the line. With regard to a fall of earth, or a slip, it is advisable to post handsignalmen if there is any likelihood of a fall or slip occurring, and, especially during wet or frosty weather, a close watch must be kept for signs of any such disturbance.

Notice should always be given to the nearest Station Master when a traction engine or similar vehicle is required to cross the line, and any failure to observe this rule by Outside Parties must be reported by the Ganger to his Inspector.

In the case of single line working being instituted, or of point or signal failure, handsignalmen are required at locations as laid down in the Rule Book. The Traffic Department often provide these, but sometimes the Permanent Way Staff may be called upon to carry out the duties of handsignalmen, and men must make themselves conversant with the rules appertaining to this work.

The duties of fogsignalmen are also laid down in the Rule Book, and will not be dealt with here. As with handsignalmen no man is allowed to act as fogsignalman who has not passed an examination in the rules applying to this work.

In addition to being required during foggy weather fogsignalmen are also needed during falling snow.

Each man before going on duty must satisfy himself that his lamps and detonators are in good order. When on duty he must be careful to stand clear of detonators, and of running lines when giving hand signals.

He should also test the signal wires occasionally by pulling on them, to see that they work freely and are not impeded by snow or other cause.

Whenever men are going to work in a position from which approaching traffic cannot be seen in time for the men to get clear, or when a large number of men are working together, a lookout man must be appointed before the work commences. The ganger or man in charge of the work must exercise his discretion as to when a lookout man is necessary, but it is essential to be on the safe side in any case of doubt.

The men selected for the posts of lookout men must be alert and quick thinking as well as having good eyesight and hearing, and they must appreciate the responsibility of their job.

On proceeding to his post, the lookout man must place himself in a position of safety from which he can obtain a clear view of all approaching traffic, and in which his attention is not likely to be diverted from his work. He should not engage in lengthy conversation, and must remember at all times that the safety of his mates depends on his concentration. He must not leave his post until relieved by another man, or until so instructed by, or on behalf of, the person who first appointed him. He must also transfer his badge to the man who relieves him.

Where more than one gang of men are working close together it is inadvisable to have only one lookout man for all the gangs, but each should have its own lookout man, who is primarily responsible for that gang alone, and who must act as though there were no other lookout man about, and not rely on the others to look out for him.

No man is allowed to act as a lookout until he has passed an oral examination in the rules applicable to lookout men, and he must be periodically tested in his knowledge of them.

ENCROACHMENTS.

Although the boundaries to Railway Company's property are usually clearly defined by standard fences, there are occasions when the land outside these fences is Railway owned, particularly so where quick hedges are planted, as these are usually positioned a few feet inside the boundary in order that men do not have to trespass when trimming them.

In such cases the boundary is usually marked with rail stumps at intervals, and runs straight between these.

Where any doubt exists the Inspector and ganger should take steps to find out the exact position of the boundary in order that encroachments may be prevented.

The usual types of encroachments for which a watch should be kept are the building of structures, erection of fences, construction of roads or footpaths, tipping of materials, excavation for laying drains or mains of any sort, and all cases of trespass such as the use by vehicles of railway property other than at places to which the public normally has access.

In any encroachment of which the ganger becomes aware, or in any case about which there is doubt, a report of the circumstances should be sent to the Inspector, giving details of the occurrence, the name and address of the person responsible for it, and a sketch of the site.

CHAPTER V.

RENEWAL OF TRACK.

British Railways expend considerable sums of money annually in either partial or complete renewal of permanent way, and the methods in general use in renewing track are described in the following pages.

Every year each Railway compiles a statement of the length of track to be renewed during the following year. Generally the statement is compiled from recommendations submitted to the Chief Engineer by the Divisional Engineers, and these in their turn are compiled from the proposals submitted to the Divisional Engineers by the Permanent Way Inspectors.

Each Inspector, therefore, must keep a close watch on the general condition of all the track on his district so that every length which, in his opinion, requires renewal should be included in his proposals. In this connection, the Inspector should bear in mind that, as the programme is prepared a year in advance, as much as two years may elapse before any length of track which he recommends is renewed.

The chief factors which determine whether a length of track requires renewal are :—

(1) The condition of the rails.
(2) The condition of the sleepers.
(3) The condition of the fastenings.

With regard to factor (1), the amount of wear allowable in a rail before the rail should be renewed varies considerably due to the differences in loads and speeds over various lines. Other conditions being equal, rails in secondary routes are allowed to remain in the track till they have worn to a considerably greater extent than is allowed in main lines. As a rough guide it may be stated that a length of track in a main line may be considered for renewal when the rails have lost 10% of their original weight, whilst on secondary lines rails may be allowed to remain until they have lost 15% or more of their original weight, though local conditions govern the matter to a large extent. An important factor is the rate of wear, as for example, rails which have lost 10% of their original weight in a few years should be renewed before rails which have lost the same amount after being in the track for a longer period.

Inspectors generally have not the necessary appliances for obtaining the weights of rails, and they must, therefore, depend on the depth of the rails as measured by calipers, as a comparative measure of the wear. In most cases this is quite reliable, though as explained on page 37, in certain localities the general wastage of the rail due to chemical action takes place fairly rapidly over the whole area of the rail. In such cases the Inspector must allow for this in submitting his proposals of track to be renewed. Before the proposals are submitted to the Chief Engineer the average weights of the rails of each length of track concerned are measured, generally by one or other of the methods explained on p. 40 *et seq.*

With regard to factors (2) and (3), the Inspector has to use his own judgment, being influenced by the amount of time which has to be spent on maintenance of any section, which naturally increases as the age of track increases and the sleepers decay and fastenings become worn.

The conditions under which partial renewal is carried out, *i.e.* the rails only or the sleepers only are renewed, are explained in the following pages.

TRAFFIC FACILITIES FOR RENEWALS.

It would be contrary to the purpose of this book were it to duplicate the books of rules and regulations issued by the Railway Administrations. The notes which follow are, therefore, intended merely as a reminder of the arrangements which may be made to permit renewals, and not as a substitute for the official rules, which must be carefully studied and followed.

Whenever the Engineering Department has to carry out work which involves an obstruction to the passage of trains, all provisions must be made, in accordance with the rules, for preventing the approach of trains. There is no difference, from this point of view, between possession of the line for a whole day or night and possession " between trains ". The only difference is in the length of time available. Work " between trains " thus consists of a series of short and independent periods of possession, separated by waiting periods during which the men and tools remain on the site. No diversion of trains or single-line working is necessary.

When possession is given for a long period, one of the following conditions may apply :—

(1) If the line is single, all traffic must be cancelled or worked by another route.

(2) If the line is double, and the work affects both lines, trains must be cancelled or diverted.

(3) If the line is double, and the work affects one line only, the traffic of both lines is worked over the unaffected line under the " single-line-working " regulations. If a crane is used on the ' dead road ', and it might, in swinging, foul the line over which single line working is in operation, arrangements must be made to block the single line between trains for the periods when the crane fouls this line.

(4) If there are more than two lines, and any two lines remain open to traffic, those two lines may be worked as the Up line and the Down line respectively, subject to compliance with single-line working regulations in respect of a line over which trains run in a direction contrary to the normal usage of that line.

Condition (3) is the one most commonly found in this country. Ballast trains and cranes may be used, in these circumstances: (1) on the two broken ends of the " dead road ", the portions of track which lie between the obstruction and the detonators being equivalent to sidings; and (2), " between trains ", on the " single-line ", with the authority of the Pilotman.

When intervals between trains are long enough, a ballast train may be taken into a section (*i.e.* outside station limits), during ordinary working, being either drawn forward to the next loop or propelled back to the box in rear under a " Signalman's wrong-line order ".

When work is being carried out between trains in a position whence the Inspector cannot readily communicate with a Signalman, it is desirable that a field telephone should be installed, in order to permit every suitable interval between trains to be fully utilised. The telephone is wired up, usually on the " omnibus circuit ", by the telegraph Lineman. The provision of telephone communication does not, however avoid the necessity for flagmen to protect the obstruction.

PREPARATION FOR RELAYING.

In order to save time during the period of occupation of the line it is worth while to take considerable trouble to ensure that the material is unloaded exactly opposite the position where it will be laid in. Where plain line is to be relaid, the Ganger (or other person detailed for the work), taking with him one man, a steel tape and a piece of chalk, should accurately mark out the positions of the new rail-joints. A compound stick may be used instead of a tape, but four men

are needed to carry it. The lengths marked out should be the length of the new rail together with one expansion space. On a curve, the rail lengths should be set out along each rail, starting from a point on the straight where the sites of two joints have been set out opposite one another by means of a square. The square is used at each joint to determine the amount by which the low rail is gaining over the high rail. When this amount first comes over $2\frac{1}{4}''$, the joint which has just been set out on the low rail should be set back $4\frac{1}{2}$ in. (A special short rail (*see* p. 210) would be inserted here during relaying), and the normal lengths of rail then marked out until the low rail leads by $2\frac{1}{4}''$ again.* The position of the short rails should be marked in chalk on the web of the old rail, facing the side on which the material will be unloaded.

It is a great advantage to have the positions of the new sleepers marked in advance for the benefit of the men carrying them in during the occupation. Where there are two or more lines the positions of the centres may be marked in paint on the side of the top flange of the near rail of the line adjoining that which is to be relaid. Alternatively sleeper centres may be marked on conductor rails, platform walls or retaining walls where such exist. In the case of point and crossing work the lengths of the timbers required at each point should be marked. The marking out may be done with a linen tape, but, to save mental calculations, it is helpful to use a lath or cord marked with the standard sleeper-spacings for one rail-length of plain line.

All fishbolts and other fastenings which will require to be taken out during the main operation should be worked during the previous week and, if any prove troublesome, they may be oiled. If the webs of the rails are much corroded it may be found necessary to drive out the keys and re-insert them, one at a time.

After the new material has been unloaded from the material train, preferably a day or so previous to the actual renewal, the relaying gang should lay it out by the side of the line in such a way as to make it convenient for lifting into the road and yet be clear of loading gauge and of spaces normally used as walking ways. Rails are usually laid in pairs in the cess or six foot for complete relaying, or separately on the sleeper ends for rerailing (in order to minimise the carrying necessary during rerailing). Sleepers, whether chaired or unchaired

* Except on the G.W.R. where the special rails used are 3″ shorter than standard rails. In measuring out, when the lead of the low rail joint over the high rail joint reaches $1\frac{1}{2}''$, a special rail 3″ shorter than standard is marked out. Standard rail lengths are then marked out on both rails until the low rail joint again leads by $1\frac{1}{2}''$

should be laid end-on to their future positions wherever site conditions permit. Where this is not possible owing to obstructions, or to steep side slopes, they should be stacked in piles of about seven opposite to where they will be used. When unchaired sleepers are used care must be taken to lay them the right way up. All sleepers laid alongside the track should be covered with soil or spent ballast as a precaution against fire. Fishplates and fishbolts are placed opposite to the new positions of the joints. Owing to the risk of loss by pilferage or accidental burying these and the keys are not usually laid out until just before being required. Keys may be distributed in bags containing sufficient for one or two rail lengths, or they may be laid out in the opposite four foot.

To save time during the actual relaying, the ballast is usually opened out to the level of the underside of the sleepers during the two days preceding the operation. This necessitates a speed restriction being imposed, as the road might be thrust out of line by trains travelling at high speed in the absence of ballast around the sleepers.

If the top ballast is " spent " and, therefore, unfit for re-use in a running line it is loaded up, unless it can be otherwise disposed of. If it is possible to get a ballast train in before the week-end occupation it may be loaded up directly, double handling being saved by having the train on the line adjoining that which is to be relaid. Two men can load one wagon without getting in one another's way. The loosening of the ballast with picks should be done beforehand.

If the ballast is dirty but not " spent ", the good ballast may be placed in the six-foot way and in the four-foot way of the adjoining road with ballast forks and the dirt loaded up or thrown on the side-slopes.* If it has been well maintained by the length gang it will be sufficient to shovel out the clean ballast to the six-foot side, only the doubtful material at the bottom being thrown to the cess side for later riddling.

UNLOADING OF MATERIAL.

Rails are conveyed on bolster wagons. To unload them at the side the uprights are removed and the rails skidded over to the edge with bars. If there is no risk of damage, either to the rails or to appliances fixed on the ground, they are dropped in the cess, or six foot, if the opposite road is

* Throwing spent ballast over the edge of an embankment is often spoken of as " strengthening " the bank. This is a misleading term, for an unstable slope is not strengthened by adding material at the *top*. However, there is little objection to the practice when the slopes are stable.

protected by a flagman. When they have to be unloaded carefully, ropes may be passed under the rails at each bolster, one end being secured to the bolster and the other paid out gradually, being checked by a turn round the opposite upright. Rails must not be unloaded on the same side of the line as a conductor rail is fixed.

Considerable use is now made, for offloading rails, of the method known as 'End-offloading' by which the rails are pulled over the end of the rail wagon and drop in the four foot. The rails are offloaded in pairs, and the method is as follows: On arrival at site the brake van is detached, and the rail wagon is placed over the position in which the first pair of rails is to be offloaded. Chains are then fixed at one end to the end of the rails further from the engine, and are then anchored at the other end to the track. The engine then draws the rail wagon forward slowly and the rails are thus pulled off the wagon, and drop in the four foot, whereupon the train is stopped and set back a little ready for offloading the next pair of rails, to which the chains, having been removed from the first pair of rails, are fixed as described above.

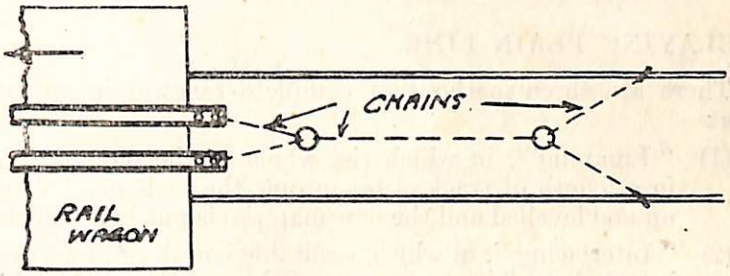


FIG. 54. TACKLE FOR END OFFLOADING OF RAILS.

Fig. 54 shews a method of attaching the chains, though there are a number of designs of tackle.

The method is particularly useful where there are obstructions in the cesses or six foot which might be damaged if rails were tipped over the side, and it is being increasingly used elsewhere.

When rails longer than 60 ft. are being unloaded, wagons fitted with 'Robel' cranes are a great advantage. These are small hand operated cranes, the rope being fitted with a special clip which engages over the head of a rail to be unloaded. The cranes are fixed to uprights at one side of the wagon, to which are attached moveable cantilevers which project slightly over the opposite side of the wagon, and on which the lifting gear can travel. A rail can thus be lifted from any part of the wagon floor and lowered to the ground

at the side. Two cranes are fitted to each wagon, and a number of wagons so fitted can be coupled together to take rails of longer lengths. The cranes should be worked in unison by orders from one man, and there is then no risk of the rails being crippled through one end striking the ground before the other.

Switches and crossings, having the chairs already attached to them when delivered, must not be dropped. Unless they can be unloaded by crane, they are lowered down skids formed of rails or sleepers propped against the side of the wagon, their descent being checked by ropes as described previously.

Sleepers are delivered either in ballast wagons or in special high-capacity sleeper wagons, whence they may be thrown. To save damage they may be run down metal skids, which are inclined brackets designed to be hooked to the wagon side. Sleepers must not be unloaded from a moving train.

Ballast is conveyed in ballast wagons of varying capacity, with low, hinged sides. Alternatively, it may come to the site in hopper wagons. (*See* p. 166).

RELAYING PLAIN LINE.

There are three methods of complete renewal in general use :—

(1) " Lumping ", in which the whole of the old material in a length of track is taken out, the beds are hacked up and levelled and the new material is put in complete.

(2) " Interlacing ", in which a suitable length of new track is laid about 6 in. to one side of the new, the ends being then linked up so as to divert traffic to the new line, the old work being afterwards removed.

(3) " Piecemeal ", in which each component of the track is renewed separately between trains.

Lumping is the method most commonly used, the lengths chosen for renewal varying from about ¾ mile, a full day's (or night's) work with complete possession, down to a single rail-length renewed in a quarter-hour interval between trains. The normal speed of working, with a gang of about 45 men,* is 100 to 120 yards per hour of uninterrupted work. Time spent in waiting for trains must be deducted, but it is not necessarily wasted, for it is only the partial rest so given which permits men to work at the pace which is usual during short occupations.

* Varies somewhat according to the length of rails and the nature of the appliances available.

Interlacing is only used where the intervals between trains are very short ; it is the most expensive method of all. Piecemeal relaying is also used where traffic is considerable. Both these methods are avoided when possible as their cost exceeds that of lumping. Precise times cannot be given, as the waiting time is proportionately large on the type of line where they are used, but generally not more than 200 yards can be done in a day.

LUMPING METHOD (WITH FULL DAY OR NIGHT POSSESSION).

In allocating the work between the members of a relaying gang, a balance has to be struck between two opposing principles. The first is that if each man is primarily devoted to one job, he will be ready when that job needs doing and will not have to be called off another job. Moreover, he will have his tools ready and will know where to find the materials he has to handle. On the other hand, all able-bodied men should take their share of the heavy and unpleasant jobs, such as carrying sleepers. It should, therefore, be clearly understood that the men who have been doing any special job should join the main gang with the heavy work as soon as they have finished their own job, and that they should work there until the Ganger or Inspector detaches them again. When there are several squads on one job (such as keying up) they should take one rail-length each and, on completion of that length, each squad should move on past the others to the next unoccupied length.

When possession of the line is obtained for relaying, most of the men spend the first few minutes knocking out the keys about four or more following them taking off the fishplates and bolts. One member of the gang should be detailed to collect these into heaps, ready for loading. The appropriate number of men are detailed to lift out the rails (say one man per yard of rail unless lifting appliances such as trestles are used). The nature of the job determines where they put them, the usual place being on the sleeper-ends of the adjoining track or in the six foot. The procedure is for the rail to be tipped inwards across the inner jaws of the chairs, either by hand or with bars. Next the rail is picked up by hand or with tongs. In lifting by hand, all the men stand on the same side of the rail ; they grip well clear of the chairs to avoid danger to their hands. With tongs they form up into pairs, one each side of the rail, each pair with a pair of rail tongs. If the rails have to be carried some distance along the line, the simplest way is to lift them only as far as the next rail which is still in position. From there they may be carried

on scooters by four men. Scooters are small trolleys which run on one rail, being fitted with two flanges to keep them upright.

All men not otherwise engaged start lifting out the old sleepers as soon as the first pair of rails are clear. For this purpose they may use sleeper tongs, " dogs ", which bite into the sleeper, or sleeper carriers, which fit in the jaws of the chairs. In either case, four men are needed. If chaired sleepers have to be lifted by hand they should first be turned over. The old sleepers must be stacked in a position convenient for loading up yet out of the way both of subsequent operations and of traffic on adjoining lines. They must not be laid in any four-foot way. Four men can carry a " length " of 24 sleepers and stack them near by in about 8 minutes, but the pace will slacken as they get tired.

The next job is picking the old beds and levelling the surface of the ballast ready for laying in the new sleepers. Four of the men who are carrying out sleepers are told off to do this work, and further groups are transferred when the work of removing sleepers is well advanced. Those who have been picking the beds the longest will be the first to turn over to carrying in the new chaired sleepers. The sleepers are set as closely as possible to their final positions, which may be marked out as previously described, or by means of a marked stick laid alongside each rail-length in turn. The sleepers are set to gauge by two men with a pair of tongs, or a special tool which hooks over the chair jaw, under the direction of the Sub-Ganger or Ganger, who accompanies them with a gauge if the line is double, setting the inner jaws 6′ $1\frac{3}{4}$″ from the outer edge of the adjoining rail. (If there is no parallel track they may be set by string line or by eye). On sharp curves it may save difficulty in tipping in rails if the sleepers for each length are temporarily laid as if for a straight line. On straight track the new rails may be laid in line close to their final position, and the sleepers put to line with a short gauge.

The new rails have now to be put in. They are first bumped once on the sleeper to shake off dirt and scale, then laid across the inner or outer jaws with their heads resting on the chair-screws and finally tipped into position. The Ganger or other leading hand takes up his position at the end of the rail and keeps the movements in unison by words of command. He may assist the tipping in with a rail-hook. Immediately each rail is tipped in he puts an expansion bit, of the correct size for the temperature of the day, on the end of the preceding rail, whereupon the man nearest to the

farther end takes a bar and, helped as necessary by the remainder of the squad, he pushes the rail up against the bit. (*See* p. 25).

A special thermometer set in a piece of rail steel should be laid in the web of one of the new rails for an hour or two before the rails are laid in. The top of the mercury in the thermometer then indicates what expansion gap is necessary, on a scale attached to the thermometer. The thermometer should be inspected at intervals during the work in case the temperature varies, and a different gap is required.

While the rails are being carried in, one man is distributing keys and another the sets of fishplates and bolts required for each joint. These men should not get in front of the rail-carrying squads, as it is dangerous to have loose material lying in the path of men carrying heavy loads. The keys at the ends of the rail are driven and the fishplates are then fixed. Alternate keys are driven next, followed by the remainder. Keying squads consist of three men, two with bars and one with a keying hammer. One holds the sleeper up to the rail with his bar under the sleeper-end, another holds the rail against the inner jaw of the chair with the chisel-end of his bar in the keyway and the third inserts and drives the key. If the keying squads find any sleeper out of square they must correct it, but it is better to have two men doing this in front of the keying squads.

When keying up is well advanced some of the men turn to shovel packing those sleepers which are obviously hanging. This having been roughly done, the ballast train is run in and enough ballast unloaded to allow the road to be lifted to its final position and packed with shovels to a top good enough to take ordinary traffic. Meanwhile, the fishbolts have been tightened up and the Ganger, having collected his expansion bits, is directing a squad of at least four to six men who, equipped with bars, are pulling the road to line.

The engine of the ballast train may be run over the length a few times and any resulting hollows are then made good, by shovel packing with the full-size ballast. The road is now ready for ordinary traffic under a speed restriction. During the next two or three days, the full strength of the gang is engaged on packing, all hollows being taken out as soon as they develop and all sleepers being packed equally hard in order that the road may stand up well without much maintenance for many years. All bolts and fastenings should be tightened up at this stage, and the road should be pulled to perfect line. Special attention should be given to the joints to avoid any possibility of the rail ends being crippled.

It remains to unload the ballast required for boxing up. The quickest method is to run over the length a train of hopper wagons with a plough attached to the brake van for spreading the ballast. The flow of ballast from the hoppers is regulated by a man walking alongside the wagon or on a platform at the end of each wagon, controlling by means of a hand-wheel the size of the opening and hence the rate of deposit. Wagons with a platform at the end have three wheels controlling the flow to the cess, four foot and six foot. Unloading is begun from the front wagon and, as each wagon becomes empty the next one behind it is brought into use, the train moving steadily forward at about two to four miles per hour. The plough under the brake van, which is lowered to spread the ballast outwards, is raised and lowered by a hand-wheel in the van. It must be raised on approaching points and crossings, level crossings, check or guard rails or any appliances which might be damaged by the flow of ballast. On approaching such appliances the hopper operator must close the outlets for a moment, unless suitable protection has been given by covering the appliances with sacking, boards or corrugated iron.

In relaying track which is electrified with a third rail it is necessary to place packings under the conductor rail to hold it in position, as it rarely occurs that the conductor and the track fall due for renewal at the same time. If the insulators are to be re-used they are detached from the sleepers and laid aside in a safe place. Where there is a fourth rail in the four-foot way it must be carried out of the way. The ballast plough cannot be used on lines fitted with conductor rails.

LUMPING METHOD (BETWEEN TRAINS).

The difference between this method and that previously described is that the line has to be made good for the passage of a train several times during the day. This involves careful organisation and good team-work, as the pace is fast during the short periods of possession between trains. A fairly high degree of specialisation is therefore called for; each man must have his job, or his sequence of jobs. In this type of work it is desirable to detail one man to stand by at the field telephone if there is no signal box near at hand, and it is almost essential to have one man whose job it is to see that the tools are in the right places when required.

The Inspector or Ganger in charge of the relaying communicates, by field telephone or otherwise, with the appropriate Signalman, Traffic Inspector or control office and, on being informed that there will be an interval of a certain duration

after the passage of a specified train, he decides how many rail-lengths to relay during that period. The gang are then distributed along that length; they knock out alternate keys (taking care that the pairs of keys left in are opposite one another, to hold the gauge) and, if four-hole fishplates are in use, they remove the two outer bolts and work the two inner ones.

When the train has passed and the man in charge receives confirmation that he may have possession, the line is blocked in accordance with Rule 217. Four men knock out the remaining keys of the first length, two of them proceeding along the remaining lengths. Another four remove the fishplates from the first four joints, two of them proceeding to the remaining joints. (These figures may be varied to suit the number of men available and the amount of work to be done).

The appropriate number of men required for handling rails of the type to be removed form a rail squad and the remainder form into groups of four for carrying out sleepers. As other jobs are finished, groups of four join the sleeper squads, "odd men out" loosening the beds with picks and levelling the ballast.

The work proceeds as described in the previous section, until the few lengths undertaken are relaid and the sleepers well packed to take the next train. All the ballast required for packing (not boxing up) may be unloaded alongside the site before the operation.

As soon as the last-but-one rail of the section is in place, the man in charge must measure with his tape the distance thence to the end of the existing rail and decide whether a closure must be cut. The hammer, set, and jim crow, or rail saw will have been placed near by in readiness by the tool man. The rails used as closures are not to be left finally in the track except at the end of the whole operation: those put in temporarily to allow a train to pass are carried forward and re-used. It is most important to see that correctly fitting junction plates are used when joining old and new rails.

The work to be done may be summarised as follows :—

Operation.		No. of men required	Squad No.	Tools required.
No.	Description.			
1	Drive out old keys ..	2	1	2 keying hammers.
2	Take off old fishplates	1 per joint.	2, 3	Ratchet spanner. Hammer (hand).
3	Turn out and remove old rails. Carry forward closure.	8 (with trestles.)*	4	2 trestles* 4 bars.
4	Carry out old sleepers.	Groups of 4.	3, 5, 6	2 carriers each.
5	Pick beds and level.	6	2, 6	4 picks. 2 rakes.
6	Carry in new sleepers.	Groups of 4.	5	2 carriers each.
7	Set sleepers in line.	2	1	6 foot gauge. Carrier.
8	Lay in new rails.	8 (with trestles.)*	4	2 trestles.* 4 bars. Expansion irons.
9	Fix new fishplates.	1 per joint.	2, 3	Ratchet spanner. Hand hammer.
10	Space sleepers. Drive in new keys.	Groups of 3.	5, 6	2 bars. Keying hammer.
11	Pack ballast.	About 30.	All	30 shovels.

* A Trestle is a framework, fitted with a lifting device, which spans the track being renewed. The lifting gear can pick up rails in the six foot, four foot, and on the cess side, and lay them anywhere in these spaces.

The column headed "Squad No." in the table on p. 168 is a tentative allocation of the members of a gang. On this basis, the numerical strength and sequence of jobs for each squad would be :—

Squad No.	No. of Men.	Sequence of Jobs.
1	2	Old keys, line sleepers, pack.
2	4	Old fishplates, pick beds, new fishplates, pack.
3	4	Old fishplates, old sleepers, new fishplates, pack.
4	8	Old rails, new rails, pack.
5	8	Old sleepers, new sleepers. } Key up,
6	4	Old sleepers, pick beds. } Pack.
	30	
	6	Flagmen, lookout, tool-man, telephone attendant, ganger.
Total	36	men.

The number of men required would preferably be more than this if the rails are moved by hand, and the arrangement of the squads would be varied accordingly.

INTERLACING METHOD.

This is a rather costly method of renewal, and its use is generally confined to places where space on the sides of the track is limited, such as in narrow cuttings, or between platforms.

The method is only really practicable when no appreciable changes in sleeper spacing, especially at joints, are necessary.

The principle of the method is to lay in the new track so that it is about 6″ to one side of the old. The old track at each end of the renewal is then linked with the new, and slewed to line up with the new, over a length of at least five or six rail lengths.

The old track is then taken out and loaded up as opportunity arises, and the new track is then slewed over to the final position.

The various operations are as follows :—

(1) The ballast is cleaned out to the level of the underside of the sleepers, and for this reason a speed restriction is necessary.

(2) The new sleepers are pulled in between the old sleepers so that they rest about 6″ to one side of the old sleepers.

Chaired sleepers may be used, in which case it is necessary to jack up the old track at one side to allow the chairs to pass under the rail.

Alternatively, the chairs at one end may be removed, and refixed when the sleepers are laid in, or plain sleepers may be used, and both chairs fixed afterwards.

The last two methods are more costly owing to the work required in fixing chairs, and also it is difficult to get a uniform gauge if the chairs are fixed on site unless machine bored sleepers are used. In very confined places it is necessary to jack up the old track on one side whichever type of sleeper is used.

(3) The new rails are put in with the same precautions in regard to expansion gaps as described for the "lumping" method. The keys are then inserted, and the fishplates put on.

(4) The gang is divided into two, and each part proceeds to link in one end of the new track with the adjacent track, and slew the ends to a line, suitable for slow running.

(5) The old material is loaded up and conveyed away from the site of the work.

(6) The new track is then slewed to the correct line.

(7) The sleepers are respaced to their correct spacing.

(8) All fastenings are tightened.

(9) The track is boxed up with the old ballast, or lifted on new ballast if necessary, and a final fettle is given to the new road.

The method is satisfactory where the traffic is moderate, and the work can be carried out by a gang of say 16 to 20 men.

Before deciding on the adoption of this method it is essential to see that proper clearances to structures and platforms exist during the interval between items 4 and 6. If they do not, the old and new track must be slewed throughout during a possession, and the new track then linked up with the old track at each end, so that the path of trains is unchanged.

PIECEMEAL METHOD.

This method is only practicable when the old track is being replaced by new track of the same type. It is very desirable to use ready bored sleepers.

In this method each component of the track is renewed separately as described below :—

(1) The new material is unloaded in the required quantities for each length.

(2) The ballast is cleaned out to the level of the underside of the sleepers, and hence a speed restriction is necessary.

(3) The old rails are removed and the new rails laid in over the complete length of the renewal. The correct expansion for the temperature at the time is allowed during this operation.

(4) The old chairs are taken off, and the old sleepers removed.

(5) The new sleepers are pulled in, the new chairs are keyed to the rails, and the chairs are screwed to the sleepers.

Four men should average between three and four lengths a day of this work, where traffic is not heavy. In narrow cuttings or between platforms it may be necessary to remove three or four old sleepers at a time, swinging them round into the four foot in order that they may be lifted clear. The new sleepers are then inserted in a similar way.

(6) The new sleepers are packed as the work proceeds.

With the exception of the loading and unloading a gang of twelve or fifteen men can do between nine or twelve lengths a day.

RELAYING WITH MACHINES.

There are a number of types of machines in use for relaying track which lift out a complete rail length of old track and reinstate a new length of track in its place. There are two main types, one of which works on the road that is being relaid, and the other works on an adjacent track to that being relaid. Fig. 55 shews the Morris tracklayer which is of the first type and Fig. 56 shews the Drouard tracklayer which is of the second type.

The new track is assembled in complete rail lengths in a depot, loaded on to special wagons, and run out to the site of work with the tracklayer. The work is commenced by removing the fishplates of the track to be renewed. The tracklayer picks up the first length of the old track and loads it on to an empty wagon. It then picks up a length of new track from the material train and places it in the space so

made clear. This is then fishplated to the end of the track which is not being relayed, and the tracklayer then moves forward and deals with the next length.

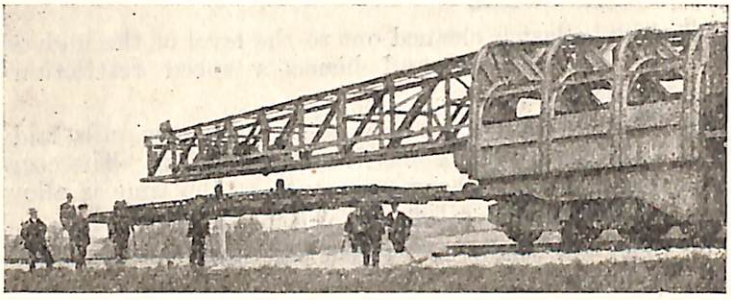


FIG. 55. MORRIS TRACKLAYER.

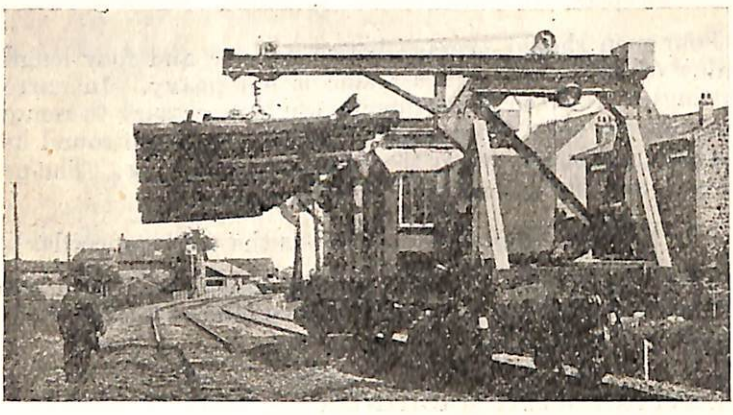


FIG. 56. DROUARD TRACKLAYER.

There are also smaller types of apparatus which deal with complete lengths of track such as the Collet-Loiseau system used in France, and the Neddermeyer system used in Germany. In both these systems a new length of track is assembled at a convenient siding, and hauled to the site of work on special bogies by a large petrol trolley. It is then exchanged for a length of old track by means of small gantries which run on rails laid specially at the sides of the track to be relaid. The whole apparatus can be quickly removed to allow for the passage of traffic.

Tracklayers have not been much used in this country except on the L.N.E.R. where a Morris Tracklayer is used. Considerable use is, however, made of these machines in America and in Europe.

Tracklayers are basically specially designed mobile cranes, and are naturally expensive machines. The advantages of this method of relaying can, however, be obtained at less cost in situations where possession of two roads can be had, by the use of a steam crane in place of a tracklayer, and this system is also used on the L.N.E.R. and Southern Railway.

RERAILING.

In many places rail wear is so severe, due to heavy traffic, side cutting, or corrosion, that the chairs, fastenings, and sleepers will last as long as two or more sets of rails.

Under these circumstances it is a general practice to renew the rails alone when they have reached the usual stage of wear, and the operation is called ' Rerailing '.

It is, of course, essential that the same section of rail be used for rerailing as previously existed.

The operation is similar to that of renewal except that generally the sleepers are not disturbed. Occasionally, however, it is found that the sleepers require respacing, on account of creep, or bad spacing in the first instance, or it may be decided to introduce extra sleepers to fit the track for faster running, or heavier loading, of trains. Under these conditions it is advisable to lift the track throughout, as when sleepers are respaced it is found that some come on the old sleeper beds, others partly on and partly off, and the rest completely off them, and this is liable to cause bad running.

If rerailing is carried out between trains suitable junction fishplates must be used when temporarily joining new rails to old to make good for the passage of a train.

Where the high-rail of a curve is sidecut it may be possible to obtain an extra lease of life for it by turning it end for end, so allowing the previously unworn edge to be run on.

The work of turning the rails is most expeditiously done by a crane, but in a station or cutting it may be necessary to load the rails on to a trolley, and run them to a place where there is sufficient room for turning. All traffic on roads which are fouled by the rails when these are being turned must be protected in accordance with the Rules.

Alternatively, the six-foot and cess rails may be transferred to the cess and six foot side respectively, without turning end for end, but this cannot be done with a short rail on the inside of a curve which would have to be turned end for end as described above.

RESLEEPERING.

(*a*) Continuous Resleepering.

On lines where the traffic is light it frequently happens that the rails last appreciably longer than the sleepers and fastenings, and in such cases, it is often an economical proposition to renew the sleepers before the rails. The operation is known as ' Continuous Resleepering ', and is equivalent to complete renewal, except that the same rails are re-used.

It is more usual to employ sleepers that have been already chaired with new or secondhand chairs at a depot, than to re-use the existing chairs, as it is difficult to ensure a good gauge when the chairs over a long length are fixed on site.

If during resleepering, the sleepers need to be respaced, and the rails are severely chair galled, difficulty is sometimes found, as if a chair when respaced comes partly under and partly off an old chair seating, the rail will not have the full bearing on the new chair.

This point should be borne in mind when deciding whether a length of track should be resleepered or renewed, though it should not arise if the sleeper spacing of the old track has been well maintained.

It is generally decided to lift the track whilst continuous resleepering is carried out, and this should be done in any case when much respacing of the sleepers is necessary.

(*b*) Spot Resleepering.

The operation of renewing a sleeper that has decayed earlier than the adjacent ones, or has been damaged, is known as ' Spot Resleepering '.

Plain sleepers are used for this, and where it is anticipated that the remainder of the track or sleepers will be renewed within a few years Grade 1 secondhand sleepers are generally used. Otherwise new sleepers should be used.

To renew a sleeper with spiked or chair screwed track, the spikes or chair screws should be withdrawn, the chairs slid along the rail clear of the sleeper. After the ballast in the beds on each side, and at the end, of the sleeper has been moved, the track is jacked up slightly and the old sleeper drawn out. As the new or Grade 1 sleeper may have a greater depth than the old, it is advisable to loosen the sleeper bed with a pick, otherwise when the track is lowered, the sleepers on each side of the new one may be ' swinging ', *i.e.* not hard on their beds.

The new sleeper is then pushed into place, the chairs slid back over it and refixed, the keys tightened up, and the track then lowered.

It will probably be found that the new sleeper should be shovel packed, and the ballast can then be replaced.

With through bolt fastenings the operation is practically as above, except that the track has to be jacked up high enough to allow the chairs to be slid over the tops of the through bolts, or alternatively, sufficient keys may be knocked out to allow the rails to be raised up, leaving the sleepers undisturbed.

POINT AND CROSSING RENEWAL.

The renewal of point and crossing work is often rather more complicated than the renewal of plain line, as more preparatory work is usually required and as normally the work is of small extent, careful organisation of the man power is necessary.

When points and crossings are renewed the opportunity is usually taken to make any improvements in the layout that may be desirable, and a plan shewing these is prepared by the Technical Staff.

Where no alteration in layout is required and the layout is not complicated it may not be necessary to set out the work beforehand.

In other cases, however, this is essential, and if there is no room by the side of the old work a convenient open space should be chosen in which the new work can be laid down exactly as it should be when put in the track.

Where the main line is curved, this curve should be accurately reproduced on the setting up ground. This may be done either by versines as described in Chapter VII, or by setting up a straight line on the site of the work, and measuring the offsets from this to the rail at frequent intervals. The new main rail can then be laid down to these offsets from a straight in the setting up yard, and lined up by eye.

A start can then be made with putting down the timbers at their correct spacing followed by the various switches and crossings at their correct leads in accordance with the plan of the work if one is provided, or if not, to standard leads. These leads must then be carefully noted, and marked on the plan, or on a sketch, and the overall length of the work checked.

A visit must then be paid to the site of the work, and the positions of the various switches and crossings marked out on site. The length of as many closure rails as possible must then be measured, allowing for the correct expansion gaps. This applies more particularly to the closure rails which are curved. The lengths of the straight ones can be obtained direct on the setting out ground.

If pegs are used to indicate the positions of the new switches and crossings, it must be borne in mind that the new timbers for these units will come on top of them. For this reason two marks should be established, either on pegs or on fixed objects, one on each side of each original peg, and well clear of the new work, in such a position that a string line passed over these marks will pass over the peg. A dimension should then be taken from the peg to one of these marks. It is then a simple matter to re-establish the position of the pegs after the timbers have been laid in.

The closure rails can then be cut, and those for the main should be put in and fishplates put on first, lined up, and the chairs keyed to them at the correct chair spacing. The chairs can then be screwed down to the timbers.

The alignment of the turnout curves should then be set out, either in accordance with standard dimensions or by the methods described in Chapter VIII. In either case a number of fixed points will be obtained, and the rails at these should be keyed to the chairs and the chairs screwed down. The lengths of rail between these points can then be keyed in to correct alignment, and held there by bars whilst the remainder of the chairs are fixed. As many fixed points on the curve as possible should be obtained, and, when a string line is used, the work should be done on a calm day, as a strong wind will deflect a long string line.

The whole of the chair screws and fishbolts should then be tightened up, and any adjustments, either to alignment or other details, carried out, although, if the original setting out is done carefully, none should be required. Time spent in making a thorough job of the preliminary setting up is saved at the time of the actual renewal when conditions are generally not so favourable to accurate working.

If there is much signalling work attached to the layout it is often advisable to request Signal Department Staff to carry out as much as possible of their work on the layout whilst it is in the setting up ground.

Whilst the layout is being assembled the man in charge of the renewal should have carefully planned the order in which the job is to be carried out, from the taking out of the old material to the laying in of the new.

If the work is to be done completely by hand, care should be taken to see that there are no obstructions to hinder the removal of the old material, or the laying in of the new.

If a steam crane is to be used for the work, a careful note must be made of any obstructions such as telegraph wires,

signal posts, retaining walls, etc., which are liable to be fouled by the jib or tail of the crane. In the case of telegraph wires it is often possible to arrange for these to be moved temporarily in case of necessity, but with other obstructions it is generally necessary to arrange positions for the crane to stand while lifting and slewing so that the jib and tail are always clear. For this reason an estimate should be made of the weight to be raised at each lift, and steps taken to ensure that the crane is capable of dealing with the various loads at the different radii at which the crane must work. When it is necessary for a complicated junction to be removed it may be an advantage to have oxy-acetylene cutters available at the time of the renewal to cut the old material into suitable sizes for handling by the crane.

A note must also be made of any superelevation that may exist on the road on which the crane will lift. If there is any, and the crane will have to work with its jib on the low rail side, it may be necessary to remove the superelevation or reduce it and/or use rail clips.

If the layout has been set up in a place away from the actual site of the work, it must be dismantled into portions of a size suitable for handling and transporting to site.

Before this is done, however, steps must be taken to see that it can be easily put together again. Each joint should be numbered, and the joint number should be marked on each rail end at the joint. The timbers should be numbered consecutively from one end of the work to the other, and the distance of each from one end of the work measured. The timber spacing so measured should, if practicable, be marked on an adjacent rail at the site of the renewal. A paint mark should be made on the rail over the centre of every ordinary and check chair where they have to be unkeyed for loading purposes. Crossing chairs may be left keyed to the crossing rails, and the chair screws and crossing screws removed, leaving the timbers bare. If a crane is used it may not be necessary to dismantle such items as pairs of switches, except perhaps in the case of long switches to remove the end timbers which may be wider than loading gauge. If possible a string line should be stretched over the timbers and a scribe mark made on each under the line. When the new sleepers are laid out these scribe marks can be put in line, thus minimising the lining up required after the renewal.

The layout can then be taken to pieces and loaded on to suitable wagons. Adjacent timbers should be loaded in batches of suitable size, and the small fittings can be loaded into the wells of the wagons, or between the bolsters.

Great care must be taken to see that the parts which will be required first at the renewal, are loaded last, so that they are the first to be unloaded. It may be necessary to request the Traffic Department to marshal the wagons into a suitable order after loading for this purpose. The route which the train will take should be ascertained as it may, in traversing connections, arrive with the wagons in the reverse order from which it started.

When the actual renewal is begun a start is made by breaking up the old layout, after the signalling gear has been disconnected, and either stacking the old material clear of the new work, or loading it by crane into empty wagons. Some of the new material may have to be unloaded first, to provide empty wagons into which the old material can be loaded.

As soon as a reasonable space is cleared, the old timber beds should be loosened with a pick and the new timbers laid down opposite the marks on the adjacent rails, or in accordance with the measured spacing. They should be placed in line and squared. The switches and crossings can then be put down as the timbers are laid down for them, followed by the chairs for the remaining rails. It is advisable to use the chair gauge when setting the chairs even though the screw holes already exist in the timbers. The remaining rails are then tipped in, and the whole is keyed up, the fishplates fitted, and all the chair and crossing screws tightened.

If possible, facing points should be laid in first, in order that the Signal Department Staff can get ahead with their work.

It is occasionally an advantage to get one rail fixed and lined up first, as it is not an easy matter to slew a lot of heavy point and crossing work that is tied together.

The scribe marks on the timbers are a help in this, as a string line placed over them will shew what slewing is required.

When all the new work has been assembled it should be fettled, and then all the switches and locking apparatus should be tested by the Signal Department to ensure that all work smoothly, and that the switch tongues close properly against the stock rails.

All that then remains is for the layout to be boxed in with ballast, and the old material cleared away, if possible during the same possession as the actual renewal.

It is not practicable to give the particulars of the numbers of men required and time taken for the renewal of various types of point and crossing work, as these depend very largely on site conditions, such as the amount of room available for storage of material, and the numbers of adjacent roads that are available for the material trains and crane.

Careful planning is necessary to ensure that sufficient time and labour are available, that tools are in their required place at the right time, and that each man knows his job and does not have to waste time waiting for other men to finish one job before he starts. In addition careful co-operation with Traffic Department is required to ensure that the material trains and crane arrive at the right time.

On large jobs it is often worth while to roster two gangs to work overlapping shifts, both gangs being on the job together during the middle period when the new material is being carried in. Towards the end, when the new work is being put in line and screwed down, the men who came on duty first are released.

DISPOSAL OF OLD MATERIAL.

When a section of track has been renewed, the old material taken out should be carefully sorted so that the greatest possible use may be made of it.

It frequently happens that a length of track removed from a main line with heavy traffic, may be quite suitable for relaying a branch or goods line where the traffic is lighter. In this case it is desirable to number the joints consecutively from one end to the other, the sixfoot and cess rail joints being distinguished, and the number of the joint marked on each rail end and on the fishplates. The track can then be laid in the same position as it occupied in the main line, and so avoid rails of different wear being fished together which would lead to bad running, and might result in broken fishplates. It is then necessary to exercise care in loading and offloading so that the rails are offloaded in the correct order.

If the whole of the material cannot be used in this way the components must be sorted separately. The rails may be graded according to their weight and general condition into groups suitable for re-use in running lines, goods lines, marshalling sidings, stabling sidings, conversion into posts for various purposes, or for sale as scrap. The sleepers would be sorted into various grades, known as Grade 1, 2, 3, etc., and Firewood. Grade 1 sleepers would be sleepers suitable for re-use in main lines for spot resleepering, and the other grades would be suitable for use on secondary, and goods sidings, as for the rails. Old sleepers may also be used amongst other things for temporary roadways, and sleeper crossings.

The chairs would be sorted into those suitable for re-use, and those unfit for further service. The former would be sent to a depot and refixed to new sleepers for use in resleepering, and the latter would be sent to a foundry where,

with a certain amount of pig iron, they would be melted down and the metal so obtained would be used for casting new chairs.

Keys, fastenings, and fishbolts should be sorted into those suitable for re-use, and those for scrap.

Fishplates may be suitable for re-use, or if they are not too badly worn may be sent to a depot for reconditioning (*see* p. 23). The remainder should be disposed of as scrap.

There is usually a considerable amount of useful material recovered from switch and crossing renewal.

Common and obtuse crossings can frequently be reconditioned by welding, if the wear is not too severe, as can switch tongues. Switch and crossing chairs, fastenings, keys, fishplates and fishbolts should be dealt with as described above for plain line materials. The timbers should be carefully inspected to decide the best use that can be made of them. If they are not too severely worn, the holes can be filled with ' Philplug ' plastic compound, or otherwise plugged and the timbers can then be used again in less important positions. It may be found desirable to turn them over if the chair seatings are worn. It often happens that a long timber is not decayed throughout its length and it is frequently possible to cut shorter timbers of sound wood from partly decayed long timbers. If the short lengths so obtained are not long enough for re-use in switch and crossing work, two such pieces may be spliced and bolted together to form one timber. When spliced timbers are used it is necessary to arrange that no two adjacent spliced timbers are laid so that the splices come in the same four-foot.

If the switches and crossings themselves are too much worn to be re-used, the small fittings such as stretcher bars, switch anchors, studs, bolts and blocks can generally be re-used.

As it frequently happens that, after a renewal has been carried out, there is no immediate use for the recovered material in the locality, many central depots are maintained to which all recovered material from a surrounding area is sent, and where it is sorted and dealt with to the best advantage by men specially detailed for the work.

No recovered material, whether it is to be dealt with locally or at a depot, should be left lying about at the site of the renewal, as, besides it being a source of danger to men walking on the line, its condition would deteriorate.

CHAPTER VI.

USE OF SYMBOLS AND FORMULÆ.

ARITHMETIC.

To enable this and the following chapters to be understood, a short explanation of the principles of arithmetic is given below. It is recommended that those readers who have difficulty in understanding the following chapters should study one of the books on Elementary Arithmetic, of which there are many available at very low cost.

A number of signs are used in arithmetic as follows :—

$16+8$ is read as " 16 plus 8 " and means the sum of 16 and 8 .. .. i.e. 24

$16-8$ in read as " 16 minus 8 " and means from 16 deduct 8 .. .. i.e. 8

16×8 is read as " 16 multiplied by 8 ", or " the product of 16 and 8 " .. .. .. i.e. 128

$\frac{16}{8}$ or $16\div8$ is read as " 16 over 8 " and means 16 divided by 8 .. .. i.e. 2

8^2 is read as " 8 squared " and means 8 multiplied by 8 .. .. i.e. 64

$\sqrt{16}$ is read as " the square root of sixteen " and means that number which when squared will give 16, i.e. 4, since 4^2 is 16.

$=$ is read as " equals ".

$\therefore$ is read as " therefore ".

( ), or { }, are known as pairs of brackets and the quantities between each pair must be worked out before adding to, or multiplying by, etc. quantities outside the brackets.

For example :—$16\times(16-8)=16\times8=128$. (This expression is often written $16(16-8)$ the $\times$ sign being omitted before brackets).

$$12-\frac{18}{(9-6)}=12-\frac{18}{3}=12-6=6$$

$$4\{10-2(5-3)\}=4\{10-2\times2\}=4\{10-4\}=4\times6=24.$$

Similarly numbers connected by $\times$ or $\div$ signs must be worked out before adding to or substracting from other quantities.

Thus in the last example above we have an expression $10 - 2 \times 2$, in which from 10 we have to subtract the product of 2 and 2.

In the same way $19 - 45 \div 3 + 2 \times 6 = 19 - 15 + 12 = 16$.

The horizontal line of the square root sign may be extended to cover a number of figures or expressions and means that the square root of all the expressions under this line is to be taken, i.e.

$$\sqrt{6 \times 8 - 24 \div (7 - 5)} = \sqrt{48 - 24 \div 2} = \sqrt{48 - 12} = \sqrt{36} = 6$$

When one number is written over a horizontal line, and another number is written under the line, the expression is called a fraction, thus $\frac{3}{8}$ is a fraction. When the top number, called the "numerator", is less than the bottom number, called the "denominator", the expression is less than 1 and the fraction is called a vulgar fraction.

When the numerator is greater than the denominator the fraction is more than 1, and is called an improper fraction.

For example $\frac{25}{8}$ is an improper fraction. To express this as a whole number and a vulgar fraction, divide the numerator by the denominator. The figure so obtained is the whole number and the remainder is then the numerator of a vulgar fraction with the original denominator.

Thus to express $\frac{25}{8}$ as a whole number and vulgar fraction:—

$\frac{25}{8}$ = 25 divided by 8, i.e. 8)25(3

24

—

1 remainder.

$\frac{25}{8}$ is therefore equal to $3 + \frac{1}{8}$, which is written $3\frac{1}{8}$.

To express a whole number and vulgar fraction as an improper fraction multiply the whole number by the denominator of the vulgar fraction and add the numerator to the result. The sum then placed over the denominator is an improper fraction.

For instance to express $2\frac{5}{16}$ as an improper fraction multiply 2 by 16 and add $5 = 2 \times 16 + 5 = 32 + 5 = 37$. Then $2\frac{5}{16} = \frac{37}{16}$. An examination of a two-foot rule, with inches divided into sixteenths, will demonstrate this point.

If in any fraction the numerator and denominator can both be divided by the same number, this may be done without altering the value of the fraction. For example in the fraction $\frac{12}{16}$, 4 will divide into the numerator and denominator, in other words the fraction will 'cancel' by 4. In figures $\frac{12}{16} = \frac{12 \div 4}{16 \div 4} = \frac{3}{4}$, and again a two-foot rule will show the truth of this.

The converse of the above is also true, i.e. the numerator and denominator of a fraction may be multiplied by the same number without altering the value of the fraction; for example $\frac{3}{8} = \frac{3 \times 8}{8 \times 8} = \frac{24}{64}$.

To add or subtract fractions they must all be brought to the same denominator, which means it is necessary to find a number into which each of the denominators will divide, and the simplest way of doing this is to multiply the denominators together and use the result as the common denominator; thus $\frac{5}{8} + \frac{3}{4} - \frac{5}{6} = \frac{120}{192} + \frac{144}{192} - \frac{160}{192}$ which is usually written $\frac{120 + 144 - 160}{192} = \frac{104}{192}$. This will cancel by 8 to $\frac{13}{24}$.

It will be noticed that the smallest number which can be divided by 8, 4 and 6 is 24, and this is known as the least common multiple. The rules for finding the least common multiple are given in books on arithmetic, but for permanent way work where fractions of an inch are chiefly dealt with, the least common multiple is usually obvious by inspection.

To multiply fractions together multiply all the numerators to obtain the final numerator, and multiply all the denominators together to find the final denominator, after having cancelled any number which will divide into both a numerator and a denominator.

For example :—

$$\frac{^{3}\cancel{21}}{4} \times \frac{\cancel{5}^{1}}{\cancel{8}_{2}} \times \frac{\cancel{5}^{1}}{\cancel{7}_{1}} \times \frac{\cancel{8}^{1}}{\cancel{10}\,\cancel{2}_{1}} \times \frac{\cancel{2}^{1}}{\cancel{5}_{1}} = \frac{3}{8}$$

In this example 7 will divide into the numerator 21 and denominator 7 which are crossed out and the result placed by the side. Similarly 3 divides into 3 and 6, 5 divides into 5 and 10, and there is a numerator 2 which cancels with the

2 remaining after 5 is divided into 10, and there is a numerator 5 and a denominator 5 which cancel.

To divide one fraction 'A' by another 'B', the fraction 'B' by which the division is to be made must be turned upside down, so that the numerator becomes the denominator and the denominator becomes the numerator, and the fraction 'A' must then be multiplied by the resulting fraction, thus :—

$$\frac{3}{4} \div \frac{2}{5} = \frac{3}{4} \times \frac{5}{2} = \frac{15}{8} = 1\tfrac{7}{8}.$$

To find the square root of a fraction the square root of the numerator must be placed over the square root of the denominator, thus :—

$$\sqrt{\frac{25}{64}} = \frac{\sqrt{25}}{\sqrt{64}} = \frac{5}{8}$$

USE OF DECIMALS.

For most permanent way calculations the use of fractions is laborious, and the work is greatly simplified by the use of the decimal system.

The principle involved in decimal figures consists merely in extending the method of expression used for whole numbers into the realm of fractions.

Thus the number 452 means 4 hundreds, 5 tens, and 2 units all added together, and the position of a figure determines whether it means units, tens of units or hundreds of units. It is, therefore, quite reasonable to make the position of a figure determine whether it means tenths, hundredths, thousandths, etc., of a unit. In the decimal system, a point called the "decimal point" is placed on the right of the figure representing units in any number. The first figure to the right of this point then indicates the number of tenths of a unit, the second figure the number of hundredths, the third figure the number of thousandths, and so on, and any vulgar fraction can be expressed as a decimal figure to any required degree of accuracy as will be explained later. Thus 452·16, means 4 hundreds, 5 tens, 2 units, 1 tenth of a unit and 6 hundredths of a unit added together and is identical with

$$400+50+2+\frac{1}{10}+\frac{6}{100} \text{ or } 452\frac{16}{100}.$$

If this number had to be multiplied by $4\frac{71}{100}$ the process by the ordinary rules of arithmetic would be extremely tedious and such large figures would be involved that errors could easily be made. As explained later, however, by writing

these numbers in the decimal system thus, $452 \cdot 16 \times 4 \cdot 71$, the multiplication is quite simple to effect, as below.

Addition and subtraction of quantities involving decimal fractions are carried out in exactly the same way as in dealing with ordinary whole numbers, except that one must be careful to write the quantities down in such a way that all the decimal points come under one another. Suppose it is required to add together 4·71 feet, 6·46 feet, 4·5 feet and 10 feet. They are set out thus :—

$$\begin{array}{r} 4 \cdot 71 \\ 6 \cdot 46 \\ 4 \cdot 5 \\ 10 \cdot \\ \hline 25 \cdot 67 \\ \hline\hline \end{array}$$

The 10, being a whole number, is placed so that it is entirely on the left of the line of decimal points. It will be observed that the " one to carry " from the column after the decimal points was treated in the usual way, being added to the next column to the left, the points forming no obstacle at all. Where the tenths and hundredths columns are left blank, as in the case of the 10 in the example, the blanks are treated as they were mere ciphers (A figure 0 is a cipher).

Two examples of subtraction are given below :—

$$\begin{array}{rr} 179 \cdot 75 & 249 \cdot 13 \\ 47 \cdot 72 & 12 \cdot 46 \\ \hline 132 \cdot 03 & 236 \cdot 67 \\ \hline\hline \end{array}$$

·03 in the first example means 3 hundredths of a unit.

To multiply, proceed as with ordinary numbers, forgetting about the decimal point. Then, the usual process having been completed, insert a decimal point in the answer in such a position that there are as many figures after it as there are *altogether* after the points in the quantities multiplied together, thus :—

$$\begin{array}{r} 452 \cdot 16 \\ 4 \cdot 71 \\ \hline 45216 \\ 316512 \\ 180864 \\ \hline 2129 \cdot 6736 \\ \hline\hline \end{array}$$

If the answer is required to hundredths of a foot, the first two figures after the decimal point only need be retained. See Example 1 on p. 187.

To divide decimal figures first move the decimal point in the divisor (the number by which the division is made) to the right hand so as to make it a whole number then move the decimal point in the dividend (number to be divided) the same number of places, to the right.

It will be seen that this is equivalent to multiplying the divisor and dividend by the same amount, which, as explained on p. 183 for fractions, does not affect the result.

Moving a decimal point one place to the right is equivalent to multiplying the figure by 10. Similarly multiplying by 100 moves the decimal point 2 places to the right, by 1000 moves the decimal point 3 places to the right and so on.

If there are more figures after the point in the divisor than in the dividend add the required number of noughts to the end of the dividend, as shewn below :—

$\frac{343 \cdot 472}{7 \cdot 25}$ is set down as 725)34347·2(

$\frac{710 \cdot 528}{6 \cdot 4634}$ is set down as 64634)7105280(

The procedure followed is then the same as in ordinary long division, but the decimal point is inserted in the answer or "quotient", before bringing down the first figure after the decimal point. Two worked examples are given below :—

```
725)34347·2(47·375        5280)4356·0(·825
  2900                      4224 0
  5347                      13200
  5075                      10560
   2722                      26400
   2175                      26400
    5470                     .....
    5075
     3950
     3625
```

In both examples it will be seen that after the last given figure in the dividend has been brought down, ciphers are brought down in the successive stages of the division, and this can be carried on until the required degree of accuracy in the answer is reached or until there is no remainder as at the third stage in the second example. It will be noted that the answer in this example is less than one, which is commonly found when calculating versines.

To convert a fraction into a decimal figure the numerator must be divided by the denominator, and to convert a decimal figure into a fraction with a given denominator the decimal must be multiplied by that denominator. The cases in which these operations are required in this book are converting inches to decimals of a foot, and vice versa and some examples of this are given below :—

(1) Convert $8\frac{1}{2}$ inches to decimals of a foot.

$8\frac{1}{2}''$ as a fraction of a foot $= \frac{8\frac{1}{2}}{12} = \frac{17}{24}$

$\therefore$ 17 must be divided by 24 to give the required answer, thus :—

24)17·0(·708 to three places of decimals.
16 8
200
192

It is usually sufficient to give decimals of a foot to the nearest ·01 (or hundredth of a foot, which is very nearly equal to one eighth of an inch). To do this, if the third figure is less than 5, take the first two figures alone, but if it is 5 or more, add 1 to the second decimal figure. In the above example the third figure is eight and, therefore, to two places of decimals, $8\frac{1}{2}$ inches = ·71 ft.

(2) Convert ·19 ft. to inches.

As there are 12 inches in a foot, ·19 must be multiplied by 12, i.e. $\cdot 19' = 12 \times \cdot 19'' = 2 \cdot 28''$.

This figure must be converted to inches and fractions of an inch, and, as for the reverse process in (1) above, eighths of an inch are usually sufficiently accurate, ·28″ must be multiplied by 8 and the nearest whole number in the result taken as the number of eighths, thus :—

$\cdot 28'' = \cdot 28 \times 8$ eighths of an inch $= 2 \cdot 24$ eighths.

As the decimal part is less than ·5, 2 is taken as the result.

and therefore, ·19 ft. $= 2\frac{2}{8}$ inches $= 2\frac{1}{4}$ inches.

On p. 337 of the Appendix is given a table for the conversion of inches and fractions of an inch to decimals of a foot and vice versa, which saves the labour involved in the above calculations.

FORMULÆ.

In the succeeding chapters, relationships between certain lengths and between certain lengths and angles of crossings will be established which are true in all cases. To save labour and for simplicity it is convenient to denote such quantities by

symbols or letters. As an example, on p. 199 it is shewn that the radius of a curve is equal to the chord length squared (i.e. multiplied by itself) and divided by eight times the versine of the curve on that chord. This is written $R = \frac{C^2}{8V}$ or $R = \frac{C \times C}{8 \times V}$, and in this form R represents the radius of the curve, C the chord length, and V the versine of the curve on a chord of length C. The expression as written is called a 'formula' or 'equation', and when the value of any two of the symbols R, C and V are known the value of the third can be calculated.

The use of letters to represent quantities is the basis of a section of mathematics called 'Algebra' and a number of the rules of this subject are given below.

The signs used in Algebra are the same as those given on p. 181, thus a + b means the sum of the quantity represented by a and the quantity represented by b, and similarly for other signs. a × b, meaning the product of the quantities represented by a and b, is often written ab ; and the expression 3a means three times the quantity a, or 3 × a, or a + a + a. The figure 3 in 3a is called the 'coefficient' of a. If a letter has no sign preceding it, it is always a plus quantity, thus a = + a.

Quantities enclosed in brackets must be taken together, thus (a + b) × (c — d) means the sum of a and b multiplied by the difference between c and d. In working out the above expression each term contained in the first brackets must be multiplied by each term in the second brackets, and the following rules regarding the signs of quantities multiplied together must be followed :—

$$(+a) \times (+b) = +ab$$
$$(+a) \times (-b) = -ab$$
$$(-a) \times (+b) = -ab$$
$$(-a) \times (-b) = +ab$$

To multiply (a + b) by (c — d), therefore, + a and + b must be multiplied by + c, and also by — d and the expression can be written ac + bc — ad — bd, and this is called 'extending' the expression (a + b) × (c — d).

Similarly (a + b) (a + 2b) can be extended to $a^2 + ab + 2ab + 2b^2$. In this expression we have one term ab and another term 2ab. These are called 'like' quantities and may be grouped together, thus (a + b) (a + 2b) = $a^2 + 3ab + 2b^2$.

The small figure 2 to the right of and above the a is called the 'index' of a and means that the quantity a must be

multiplied by itself, i.e. squared. Similarly $2b^2 = 2 \times b \times b$, and it should be noted that $(a + b)^2 = (a + b) \times (a + b)$, the index, being outside the brackets, indicating that the sum of a and b is to be squared.

The difference between $(ab)^2$ and ab^2 should also be observed thus :—

$(ab)^2 = (ab) \times (ab) = a \times b \times a \times b = a^2b^2$ whilst $ab^2 = a \times b \times b$. The order in which the letters are written is immaterial, i.e.

$$ab^2 = a \times b \times b = b^2a = b \times b \times a.$$

Similarly the difference between $\left(\frac{a}{b}\right)^2$ and $\frac{a^2}{b}$ should be noted thus :— $\left(\frac{a}{b}\right)^2 = \frac{a^2}{b^2} = a^2 \div b^2$

whilst $\frac{a^2}{b} = a^2 \div b$,

also $\frac{a^2}{b} \div b = \frac{a^2}{b} \times \frac{1}{b} = \frac{a^2}{b^2} = \left(\frac{a}{b}\right)^2$

The expression $\frac{a}{b} = \frac{c}{d}$ is an equation, and is sometimes written a : b : : c : d which is read ' a is to b as c is to d ', but the latter form is not used in this book.

If $\frac{a}{b} = \frac{c}{d}$ then the following operations may be performed, and the results will be equal :—

(1) The equation may be inverted, i.e. $\frac{b}{a} = \frac{d}{c}$.

(2) The numerator of the left hand side may be multiplied by the denominator of the right hand side and the product will be equal to the denominator of the left hand side multiplied by the numerator of the right hand side, i.e., $a \times d = b \times c$ or $ad = bc$. Similarly if $\frac{a - b}{a + b} = \frac{c - d}{c + d}$, then $(a - b) \times (c + d) = (a + b)(c - d)$ This is called ' cross-multiplication '.

(3) Both sides of the equation may be multiplied by the same quantity, i.e., $\frac{2a}{b} = \frac{2c}{d}$ and in general terms $\frac{az}{b} = \frac{cz}{d}$

(4) Both sides of the equation may be divided by the same quantity, i.e., $\frac{a}{2b} = \frac{c}{2d}$ and $\frac{a}{bz} = \frac{c}{dz}$.

(5) Both sides of the equation may be squared, i.e.,

$$\frac{a^2}{b^2} = \frac{c^2}{d^2}$$

(6) The square root of both sides may be taken, i.e.,

$$\sqrt{\frac{a}{b}} = \sqrt{\frac{c}{d}} \text{ or } \frac{\sqrt{a}}{\sqrt{b}} = \frac{\sqrt{c}}{\sqrt{d}}, \text{ since } \sqrt{\frac{a}{b}} = \frac{\sqrt{a}}{\sqrt{b}}$$

(7) The same quantity may be added to both sides, i.e.,

$$\frac{a}{b} + z = \frac{c}{d} + z$$

(8) The same quantity may be subtracted from both sides, i.e.,

$$\frac{a}{b} - z = \frac{c}{d} - z$$

(9) The sign of both sides of the equation may be changed, i.e.,

$$-\frac{a}{b} = -\frac{c}{d}$$

If the equation is written in the form ad = bc, i.e., the original expression has been cross-multiplied, the operations 3-9 inclusive may be performed.

$\therefore$ If both sides are divided by d we have $a = \frac{bc}{d}$

" " " c " $b = \frac{ad}{c}$

" " " b " $c = \frac{ad}{b}$

" " " a " $d = \frac{bc}{a}$

whence if the values of any three of the letters a, b, c, and d are known it is possible to calculate the value of the fourth when $\frac{a}{b} = \frac{c}{d}$, and these equations are in the form of formulæ to find a, b, c and d.

As an example if b = 3, c = 18, d = 6 we have

$$a = \frac{3 \times 18}{6} = 9.$$

$\frac{a}{b} = \frac{c}{d}$ or ad = bc is a simple equation and those found in this book will generally be of a more complex form, but in all cases the operations 1-9 inclusive may be performed, and the operations in 7 and 8 are specially useful. For example if a + (b — c) = d — 2e, we can take (b — c) from both sides

and obtain $a = d - 2e - (b - c)$. We can also add 2e to each side and obtain $a + (b - c) + 2e = d - 2e + 2e$ or $a + (b - c) + 2e = d$. ($-2e$ and $+2e$ cancel out).

It will be seen that the result in the first case has been to remove the term $(b - c)$ from the left hand side and to put it on the right hand side but preceded by the opposite sign, i.e., a $-$ sign instead of a $+$ sign.

In the second case 2e has been moved from the right side of the equation to the left and its sign changed, and, if in this case we take $a + (b - c)$ from both sides, we obtain

$$2e = d - a - (b - c), \text{ or dividing both sides by 2}$$
$$e = \tfrac{1}{2}\{d - a - (b - c)\}$$

This special case of taking the same quantity from, or adding the same quantity to, both sides of an equation is called 'transposing', and a rule may be stated thus:— In any equation, one or any of the terms on one side of the equation may be transposed to the opposite side of the equation, but the sign preceding each term so transposed must be changed. If a term transposed is included in brackets, or an expression in brackets forms part of the term, the signs of the quantities inside the brackets are not changed in transposing, the sign preceding the whole term being the only one changed.

It will be seen that from the original equation $a + (b - c) = d - 2e$, three equations have been evolved which give the value of a, d and e, in terms of the other symbols. To find the values of b and c it is necessary to remove the brackets.

If an expression included in brackets is preceded by a $+$ sign the brackets may simply be removed, i.e., $a + (b - c) = d - 2e$ may be written $a + b - c = d - 2e$.

Then utilising the rule above we have

$$b = d - 2e - a + c$$
$$\text{and } -c = d - 2e - a - b \text{ or by (9) above}$$
$$c = -d + 2e + a + b$$
$$= 2e + a + b - d$$

If an expression included in brackets is preceded by a minus sign, on removing the brackets all signs inside the brackets must be changed thus

$$-(a + 2b - c - d) = -a - 2b + c + d$$
$$= c + d - a - 2b$$
$$= (c + d) - (a + 2b)$$

In the last line the reverse process to removing brackets has been carried out, brackets having been introduced, and a similar rule applies in this case, i.e. if terms are grouped together in brackets preceded by a plus sign, the signs of the terms are unchanged, and if they are grouped together in brackets preceded by a minus sign, the sign of each term so grouped is changed.

It is often convenient when dealing with similar quantities, i.e. a number of lengths of lead, or angles of crossings, to use one letter to denote each length or angle of the same type, and to differentiate between them by means of a small number or letter called a " suffix ", to the right and at the foot of such letter.

Thus in a switch and crossing layout, the different leads may be called, for purposes of calculation, L_1, L_2, etc., and the different angles N_1, N_2, etc. Similarly in curve calculations the chord length may be called C and the sub-chord C_s.

Numerous examples of this will be found in this book.

To apply a formula to any given set of circumstances the equation should be put in such a form that the unknown quantity is on one side of the equation. The known quantities can then be substituted for the corresponding letters in the equation and the value of the unknown calculated by arithmetic. For example suppose that the versine of a curve on a chord length of 100 feet were measured and found to be 1 foot, then these values of C and V can be substituted in the formula given on p. 199 thus :—

$$R = \frac{C^2}{8V}$$

$$= \frac{100^2}{8 \times 1} = \frac{10{,}000}{8} = 1{,}250 \text{ feet,}$$

which is the radius of the curve in question.

In all formulæ the dimensions of lengths must be in the same units, i.e. all in feet, or all in inches. In the above example C and V are in feet, and, therefore, the radius R as calculated will be in feet. Certain of the *rules* given in the following chapters are for cases where the units are different.

For instance on p. 203 it is shewn that the radius of a curve in *chains* is equal to 99 divided by the versine in *inches* measured on a chord length of 66 *feet*. Such cases are always so described in this book, and in all other cases the units must all be the same in any one example, and if as measured or given they are not the same, they must all be converted to one unit before being inserted in the formula.

MENSURATION.

It is often necessary for areas of surfaces or volumes of material to be ascertained, and rules are given below for obtaining this information.

Referring to Fig. 57, to find the area of

1. *Square.* Multiply the length of a side by itself, *i.e.* $A \times A = A^2$.

2. *Rectangle.* Multiply the length by the breadth, *i.e.* $B \times D$.

3. *Parallelogram.* Multiply the length of one side by the distance to it from the opposite side (measured at right angles), *i.e.* $B \times D$.

4. *Triangle.* Multiply half the length of the base by the verticle height, *i.e.*, $\frac{1}{2}B \times H$. (It is immaterial which side is taken as the base, but the height must be measured to the base).

5. *Circle.* Multiply the radius squared by π, *i.e.* πR^2. (π may be taken as $\frac{22}{7}$ see p. 196. If the diameter is measured the rule, Area $= \frac{\pi D^2}{4}$ may be used).

6. *Trapezium.* Multiply half the sum of the lengths of the parallel sides by the vertical distance between them, *i.e.* $\frac{A + B}{2} \times H$. (This figure is sometimes called a *Trapezoid*).

7. *Irregular Shape.* If the shape has straight sides it may be split up into some or all of the shapes 1, 2, 3, 4 and 6, the area of each found as above, and the results added together.

If the shape has not got straight sides, divide it into parallel strips of width W. Multiply the length of each strip (measured on the centre line of the strip) by W, and add the results together.

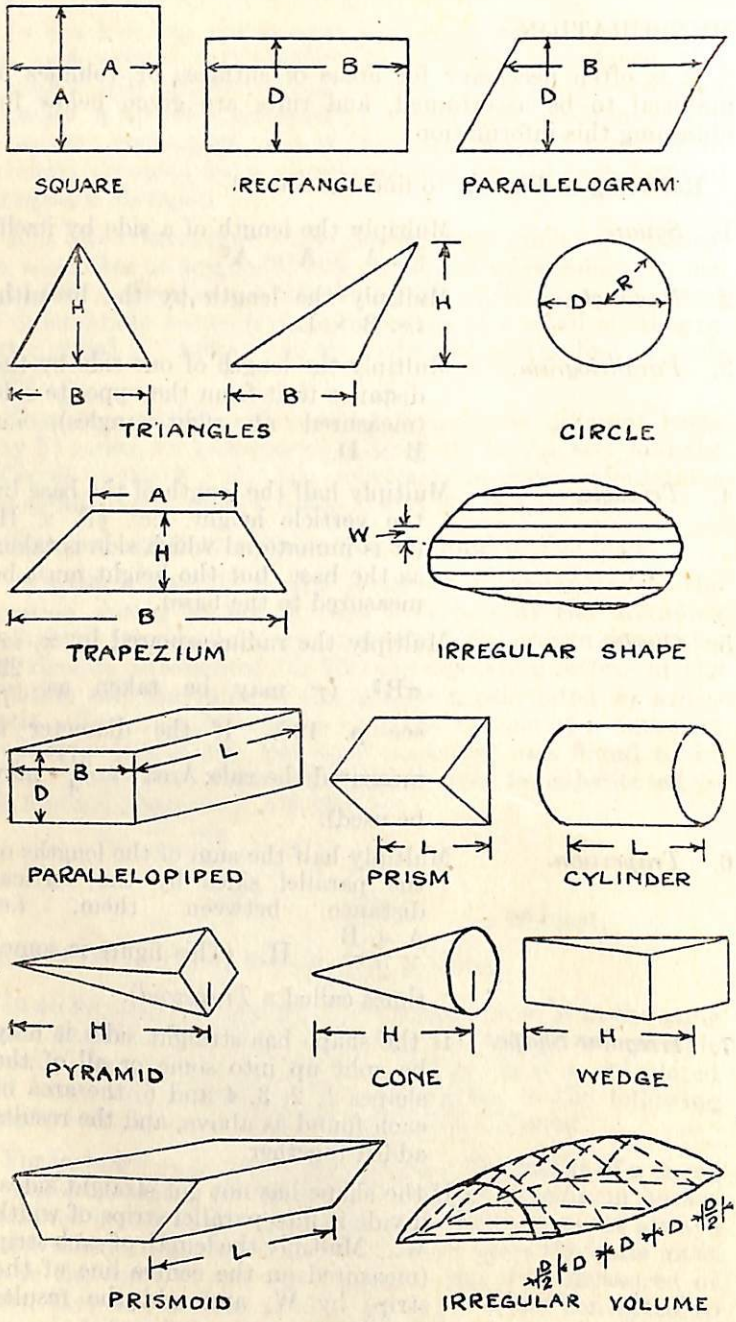


FIG. 57. AREAS AND VOLUMES.

Again referring to Fig. 57, to find the volume of

1. *Parallelopiped.* Multiply together the depth, breadth, and length, *i.e.* B × D × L. (If these lengths are all equal the shape is a *Cube.*

2. *Prism.*
3. *Cylinder.* } Multiply the area of the end by the length.

4. *Pyramid.*
5. *Cone.* } Multiply one-third of the area of the end by the height.

6. *Wedge.* Multiply one half of the area of the end by the height.

7. *Prismoid.* Multiply the length by one sixth of the sum of the areas of the two ends and four times the area of the cross section half way between. *i.e.* if the area of one end is S_1, of the other S_2, and of the mid section is S_3, the volume is $L \times \frac{S_1 + S_2 + 4S_3}{6}$.

8. *Irregular Volume.* Take cross sections at a convenient distance 'D' apart, the first being at $\frac{1}{2}$D from one end, and the last $\frac{1}{2}$D from the other. Multiply the sum of the areas of the cross sections by D.

CHAPTER VII.

CURVED TRACK.

Railway curves are generally parts of circles, and before proceeding to any practical considerations of curved track it is essential that some of the more important geometrical properties of a circle should be understood.

GEOMETRICAL TERMS.

The curved line bounding a circle is called the *circumference*. Every point on the circumference is at the same distance from the centre of the circle and this distance is called the *radius* of the circle. A line drawn at right angles to the radius at the point at which it meets the circumference is a *tangent* to the circle. From any point outside a circle only two tangents to the circle can be drawn and these tangents are equal in length. The line joining the intersection point of the tangents and the centre of the circle bisects at right angles the line joining the tangent points.

Any line drawn across the circle from one point on the circumference to another point on the circumference is called a *chord*. The chord which passes through the centre of the circle is a *diameter* of the circle and is consequently equal to twice the radius.

The diameter divides the circle into two *semi-circles*.

A piece of the circumference of a circle is called an *arc*. The area bounded by an arc and a chord is a *segment* of a circle. The area bounded by an arc and two radii is a *sector*.

The distance measured at right angles from the middle point of a chord to the arc is called the *versed sine* (generally written *versine*) or middle ordinate, and the chord joining either end of the arc and its centre point is called the *sub-chord* or the chord of half the arc. These are all shewn in Figs. 58 and 59.

There are certain definite relations between the parts of a circle which a permanent way man must have at "the tips of his fingers" even if the proofs are only at the back of his mind.

The length of the circumference of a circle is 3·14 or about $3\frac{1}{7}$ times the length of the diameter.

This value is usually denoted by the Greek letter 'pi' (π) so that the length of the circumference would be written πD or $2\pi R$, where 'D' denotes the diameter and 'R' the radius.

For all practical purposes the value of π can be taken as $3\frac{1}{7}$ of $\frac{22.}{7}$ If may be helpful to remember that the diameter of a halfpenny is one inch and the distance round the edge (i.e. its circumference) is $3\frac{1}{7}$ inches.

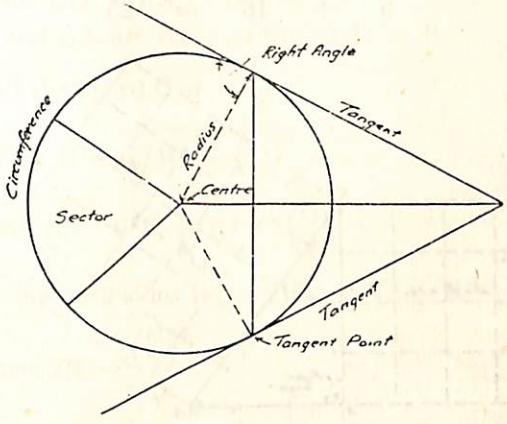


FIG. 58.

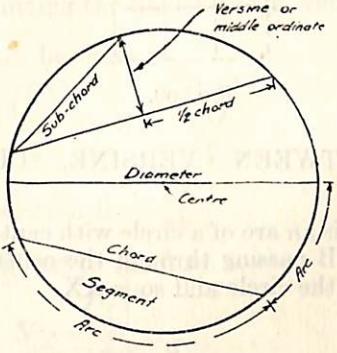


FIG. 59.

There is a very important property of a right angled triangle* which is that the sum of the squares on the sides forming the right angle, is equal to the square on the side opposite the right angle.

The diagram illustrates this in the well known case of a triangle with sides of 3, 4 and 5 units, but it must be remembered that the same rule is applicable to all right angled triangles.

* For the definition of a right angle *see* p. 200.

As applied to Fig. 60 the formula would be written :—

$$AB^2 + AC^2 = BC^2$$

or in figures :—

$$3^2 + 4^2 = 5^2$$

or $$(3 \times 3) + (4 \times 4) = (5 \times 5)$$

i.e. $$9 + 16 = 25$$

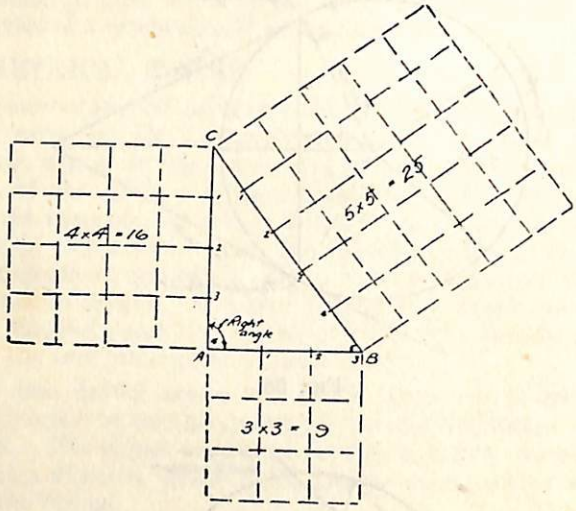


FIG. 60.

RELATION BETWEEN VERSINE, CHORD, AND RADIUS.

In Fig. 61, ABC is an arc of a circle with centre X and chord AC. The line XDB passing through the centre of the chord at D is a radius of the circle and so is AX.

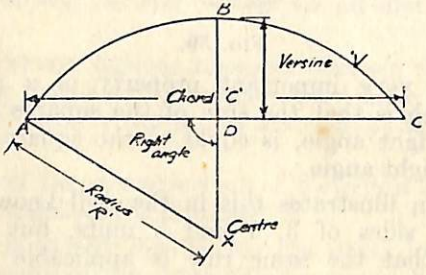


FIG. 61.

The triangle ADX is right angled at D, so that :

$$AX^2 = AD^2 + DX^2$$

or $$DX^2 = AX^2 - AD^2$$

and $$DX = \sqrt{AX^2 - AD^2}$$

The versine BD = BX — DX = V

and BX and AX are Radii of the circle = R

AD is half the chord C or $= \frac{C}{2}$

so that $V = R - \sqrt{R^2 - \left(\frac{C}{2}\right)^2}$

from which $R - V = \sqrt{R^2 - \left(\frac{C}{2}\right)^2}$

$\therefore$ squaring both sides $R^2 - 2RV + V^2 = R^2 - \left(\frac{C}{2}\right)^2$

whence $2R = \frac{\left(\frac{C}{2}\right)^2}{V} + V$

In curves with which one has to deal on Railways the versine is very small in relation to the radius and no practical difference arises through omitting the final V in the above.

The formula thus becomes :—

$$2R = \frac{\left(\frac{C}{2}\right)^2}{V} \text{ or } R = \frac{\left(\frac{C}{2}\right)^2}{2V}$$

which may be written $R = \frac{C^2}{8V}$

or can be transposed to the form :—

$$V = \frac{\left(\frac{C}{2}\right)^2}{2R}$$

$$\text{or } V = \frac{C^2}{8R}$$

Expressed in words " The versine (V) is equal to half the length of the chord squared (i.e. multiplied by itself) divided by twice the radius."

In Fig. 61 this means that :—

$$BD = \frac{AD^2}{2AX}$$

CIRCULAR MEASUREMENT.

Whilst dealing with the circle, reference must be made to its employment for measuring angles.

One is accustomed to speak of the angle of a crossing as 1 in 8, of a slope of an embankment as $1\frac{1}{2}$ to 1, or of a batter of retaining wall as 1 in 10.

This method of measuring is very simple and expressive but it is not convenient for the exact measurement of any angle.

For this purpose the circumference of a circle is divided into 360 parts and the angle contained by the radii joining the ends of one part is called a *degree* (1°). The radii dividing a circle into four equal parts are thus at an angle of 90° to each other or are said to be at right angles, i.e. a right angle equals 90°. Half a right angle (45°) is equivalent to a slope of 1 in 1.

For still finer measurement, the degree is divided into sixty minutes (′) and each minute into sixty seconds (″).

A method of describing a curve by this means will be mentioned later.

CLASSIFICATION OF CURVES.

Railway curves can be classified as (i) simple, (ii) compound or (iii) reverse.

A simple curve is of one radius throughout (Fig. 62A) and a compound curve is made up of two or more simple curves, both curving the same way or of similar flexure (Fig. 62B).

It should be observed that in compound curves the adjoining curves have a common tangent at their meeting point, and that their radii overlap at that place.

In the Fig. 62B, C_1J is the radius of the first curve, C_2J is the radius of the second curve ; C_1 C_2 J are in the same straight line and the tangent T_1 J T_2 is common to both curves at J.

Similarly C_2 the centre of the second curve is in the same line as C_3 (the centre of the third curve) and K the tangent point at which the second and third curves meet.

A reverse curve or a curve of contrary flexure can be described as a compound curve in which the radii of the adjoining curves are an extension of one another, instead of overlapping, as shewn in Fig. 62C, i.e., C_1, the centre of the first curve, J, the point at which the first and second curves meet, and C_2, the centre of the second curve, are in a straight line, and T_1 J T_2 is tangential to both curves. Similarly

C_2, KC_3 is a straight line and T_2KT_3 is tangential to the second and third curves.

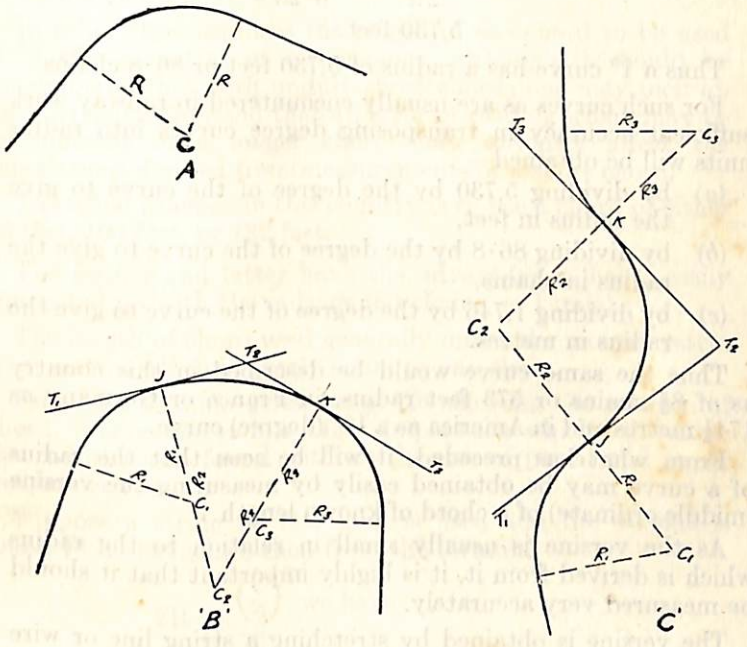


FIG. 62.

The tangent at the meeting point is again common to both curves.

If three curves are joined in this manner as in Fig. 62c they are known as a double reverse.

MEASUREMENT OF RADIUS.

In this country Railway curves are usually described by the length of the radius, sometimes measured in feet and sometimes in chains (a chain is 66 feet).

Continental practice is similar, but of course the usual unit of measurement is the metre.

The American and Colonial practice is to describe the curve by the angle subtended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections each of 100 feet. Each of these sections will thus subtend an angle of 1° at the centre.

The length of the circumference, $2\pi R$, will thus be 36,000 feet and the Radius will be :—

$$R = \frac{36{,}000}{2\pi} = \frac{36{,}000}{6 \cdot 28}$$
$$= 5{,}730 \text{ feet.}$$

Thus a 1° curve has a radius of 5,730 feet or 86·8 chains.

For such curves as are usually encountered in railway work sufficient accuracy in transposing degree curves into radius units will be obtained—

(*a*) by dividing 5,730 by the degree of the curve to give the radius in feet,

(*b*) by dividing 86·8 by the degree of the curve to give the radius in chains,

(*c*) by dividing 1,746 by the degree of the curve to give the radius in metres.

Thus the same curve would be described in this country as of $8\frac{2}{3}$ chains or 573 feet radius, in France or Germany as $174\frac{1}{2}$ metres and in America as a 10° (degree) curve.

From what has preceded, it will be seen that the radius of a curve may be obtained easily by measuring the versine (middle ordinate) of a chord of known length.

As the versine is usually small in relation to the radius which is derived from it, it is highly important that it should be measured very accurately.

The versine is obtained by stretching a string line or wire between the ends of the chord length decided upon and measuring the distance between the line and rail at the middle point of the chord. It is preferable to mark the ends and middle of the chord on the rail though they may be marked on the string. Two men then hold the string up against the rail head at the ends of the chord, and a third measures the versine at the middle point. The string line or wire should have handles at the end, so that the line can be pulled tight enough to avoid it being deflected by any breeze. The measurement should not be attempted on a windy day.

Care should be taken that the string is applied to the side of the head of the rail below the rounding or worn edge.

In measuring the versine, one end of the rule should be put under the string against the middle point already marked on the rail, and the rule brought up to a horizontal position to the underside of the string so as to damp the vibrations, but not to deflect it.

In determining the length of the chord to be used, there are many considerations.

For instance if the curve is to be described in degrees there are obvious advantages in using a chord on which the versine in inches gives the degree of the curve. The length of such a chord is 61′ 9″.

In other circumstances the length of the chord to be used is chiefly a matter of convenience, although it should be remembered that with unduly short chords one may pick up local irregularities, and that an error of reading which may be insignificant in a longer chord may seriously affect the calculations derived from measurements of a short chord.

The usual practice in this country is to use a chord of either 66 feet, 100 feet, or 132 feet.

The former and latter have the advantage of being easily connected up with the mileage (80 chains = 1 mile).

The length of chord used generally under the metric system is 20 metres which is nearly equal to one chain.

From the formula given on p. 199 showing the relation of chord, versine and radius a few simple rules which will enable the radius to be found without the use of pencil and paper can be derived.

Suppose a string 66 feet long is used and the versine is found to be 10 inches, then from the formula—

$$2R = \frac{\left(\frac{C}{2}\right)^2}{V}, \text{ we have}$$

$$2R = \frac{33 \times 33}{\frac{10}{12}} = \frac{1089 \times 12}{10}$$

$$= 1{,}307 \text{ feet nearly.}$$

$$\text{or } R = 654 \text{ feet or } 9{\cdot}9 \text{ chains.}$$

By working out a few other examples using a chord of 66 feet it will be seen that the versine in inches multiplied by the radius in chains is always 99.

From this can be derived the rule that with a 66 foot chord the versine in inches divided into 99, gives the radius in chains.

If the radius is wanted in feet then—

$$R = \frac{99 \times 66}{V} = \frac{6534}{V}$$

Similarly when a chord of 100 feet is used, the rule becomes 228 divided by the versine in inches gives the radius in chains, or 15,000 divided by the versine in inches gives the radius in feet.

When a chord of 132 ft. is used the rule becomes :—Divide 396 by the versine in inches to give the radius in chains.

As stated on p. 203 with a chord of 61 feet 9 inches the versine in inches gives the ' degree ' of the curve.

It should be noted that, in the formula $V = \frac{(\frac{1}{2}C)^2}{2R}$, for any given radius, V is dependent on the square of the chord length. This means that the versine of a curve measured on a 132 feet chord would be *four* times that measured on a 66 feet chord and *sixteen* times that measured on a 33 feet chord since $\left(\frac{132}{66}\right)^2 = 4$ and $\left(\frac{132}{33}\right)^2 = 16$.

Similarly the versine measured on a 50 feet chord would be one quarter of that measured on a 100 feet chord since $\left(\frac{50}{100}\right)^2 = \frac{1}{4}$.

Since for practical purposes the sub chord, *see* Fig. 59, is equal in length to half the main chord, the sub-versine, or versine on the sub-chord is one quarter of the versine on the main chord.

COMPLETE MEASUREMENT OF A CURVE.

So far single measurements of a curve have been dealt with, but it must of course be understood that such single measurements or even several unconnected measurements are not likely to give a correct picture of the curve in question, unless it is in perfect alignment.

If one has to examine a curve completely by this method, particularly if some question of adjustment or re-alignment has arisen, it is necessary that the measurements should be connected one to the other, and that they should cover the whole length of the curved portion of the track.

The procedure in such a case would be to fix a point well back on the straight or tangent at the beginning of the curve. The position of this point should be measured from the nearest mile post or from some fixed structure, so that it may be found again if necessary later on. (*see* Fig. 63).

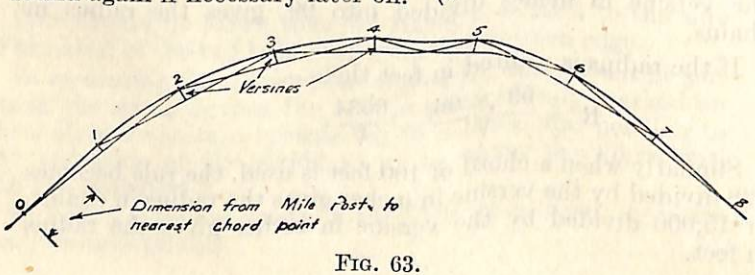


FIG. 63.

This point should be marked ' O ' and from it, distances equal to half the length of the chord which it is intended to use should be marked off on the rail and numbered ' 1 ', ' 2 ', ' 3 ', etc. This measuring should be continued until there are two points marked on the straight at the end of the curve.

In marking and numbering the points ordinary chalk should be avoided and if possible ' parcel ' crayon which is somewhat oily and not easily washed off should be used. If the marks are to be available for a long period paint should be used.

In taking the first measurement, one end of the string is applied to the side of the rail at O and the other end at 2, and the offset is measured at 1 and recorded in the book against that number.

The ends of the string are then moved to 1 and 3 and the offset measured at 2.

By overlapping the chords in this way all the information necessary for record purposes or to enable a re-alignment to be effected is obtained.

The various methods adopted for planning adjustments of curves or re-alignments are all based on some such survey of the curve as is detailed above. (*see* p. 96 for methods of curve re-alignment).

SETTING OUT CURVES.

When railway curves are set out in the first instance, an instrument called a theodolite is used. It is essentially a telescope fixed on the axis of a circular plate divided round the edge into degrees.

By the help of this instrument angles can be set out, and one of the easiest ways of fixing points on the arc of a circle is to set out the angles made by the lines joining the ends of chords to the point at which the curve begins or ends.

It is not required of the lengthmen that they should know how to set out a curve by the use of a theodolite. There are, however, a number of ways of setting out curves which are simple, and which, carefully executed, give good results.

The tools required are a string line, tape, 2 ft. rule, hammer, and a number of pegs, skewers or ' arrows '.

The first method is illustrated in Fig. 64, ST being a straight tangential to which a curve is to be set out, the tangent point being T. Knowing the required radius ' R ' of the curve, chose a convenient chord length ' C ', and calculate the value of the versine V from the rule $V = \frac{(\frac{1}{2}C)^2}{2R}$. By means of a

string line and pegs extend the straight to the point P, making TP equal in length to $\frac{C}{2}$. From P measure the distance V at right angles to TP and put a peg in at the end of this distance. This gives the point on the curve marked A in Fig. 64. From T extend the string to point B, by making TB equal in length C, and the distance between the middle of the length TB and A equal to V. This is the length AV_1 in the Figure. It will be seen that point B is then on the curve, since TB is the chord C and the versine AV_1 has been made equal to V. The string is then moved to A and point C is set out by making the length AC equal to 'C' and BV_2 equal to V.

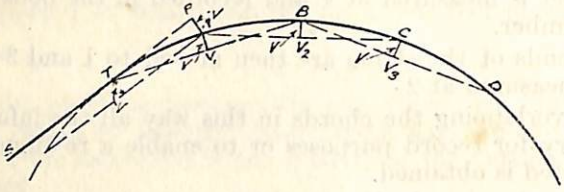


FIG. 64.

Similarly as many more points on the curve as necessary can be set out. A wide peg should be used for marking point B. This can be driven in its approximately correct position, and the string line can then be swung about T until the distance AV_1 is exactly equal to V. The string must be kept taut during this operation. A mark should be made on the top of the peg underneath the string, and a nail can then be driven in the peg to indicate the exact point on the curve. The further points on the curve should be treated similarly.

The second method is illustrated in Fig. 65. Point A on the curve is obtained in the same way as above. A string line is then stretched from T over point A, and extended to P_2 so that the length TP_2 is equal to 'C'. P_2B equal in length to 2V is then set out at right angles to TP_2 and B is then a point on the curve.

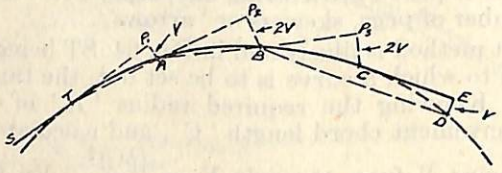


FIG. 65.

The string is then moved to A and extended over B to P_3 so that AP_3 is equal to the chord length. Setting out P_3C at right angles to AP_3 equal in length to 2V gives the point C on the curve, and so on for any further points required.

The method of setting out a straight tangential to the curve at the far end is shewn in Fig. 65. For example if point C is to be the last point on the curve, assume the curve extended another $\frac{1}{2}$ chord length to D which is set out by either of the methods described above. Then at D measure the distance DE equal to V at right angles to BD towards the outside of the curve, and set a peg at E. CE is then tangential to the curve TABC at the point C.

The two methods described above are not suitable for setting out a curve to join two intersecting tangents.

There are any number of circular curves that can be set out tangential to two tangents intersecting at a given angle. When one tangent point is fixed however, only one circle can be set out which will be tangential to both tangents. Similarly if the radius of the circle is fixed there is only one position in which the circle will be tangential to the two tangents.

In Fig. 66 OS and OS_1 are two straights which it is desired to connect by a circular curve. Assuming firstly that the position of one tangent point is given at T, then from the properties of the circle it follows that the other tangent point must be at T_1 in such a position that $OT = OT_1$.

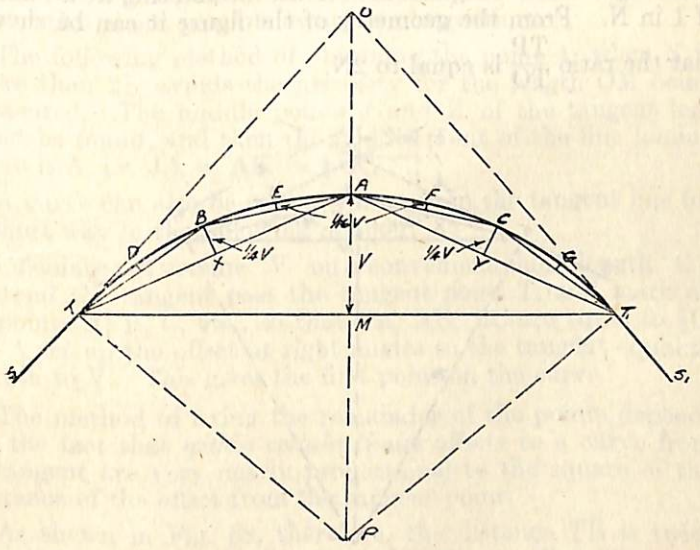


FIG. 66.

The radii at the tangent points are at right angles to the tangents and meet at P the centre of the curve. From the geometry of the figure it can be shewn that the ratio of TP to OT is equal to that of TM to OM i.e. $\frac{TP}{OT} = \frac{TM}{OM}$.

$$\therefore TP = \frac{TM \times OT}{OM}$$

i.e. the radius is equal to half the distance between the tangent points multiplied by the tangent length, and divided by the distance of the intersection of the tangents from the centre of the line adjoining the tangent points. The lengths TM, OT, and OM can generally be measured, and hence TP can be found.

The distance AM can then be calculated since it is the versine of this radius on the chord between the tangent points,

$$\text{i.e. } AM = \frac{TM^2}{2 \times TP} = \frac{TM \times OM}{2 \times OT} \text{ (from above).}$$

Joining the tangent points to A we obtain the sub chords TA and T_1A, and at the middle points X and Y of these the sub versines BX and CY each equal to $\frac{1}{4}AM$ can then be set out.

The process can be extended to obtain points D, E, F and G as shewn in the figure, the versines at these points being $\frac{1}{16}AM$.

In Fig. 67 two tangents are shewn intersecting at an angle of 1 in N. From the geometry of the figure it can be shewn that the ratio $\frac{TP}{TO}$ is equal to 2N.

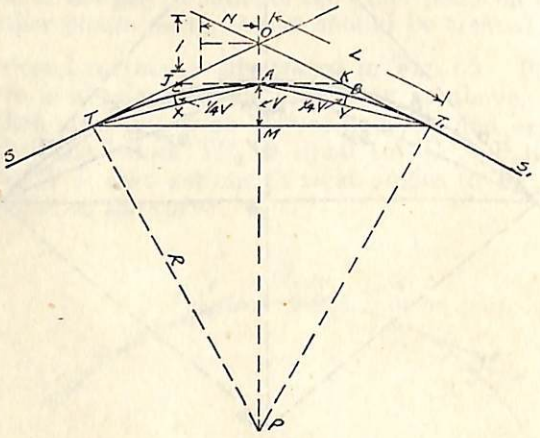


FIG. 67.

Calling the tangent length L and the radius R we have $\frac{R}{L} = 2N$, from which we can obtain R when L and N are known since $R = 2LN$. Similarly when R and N are known $L = \frac{R.}{2N}$

The formula $L = \frac{R}{2N}$, is the only one that can be used to set out a curve when the radius is fixed, as the tangent points must first be found before points on the curve can be fixed.

When the angle of intersection of the tangents is flat, i.e. N is more than about $2\frac{1}{2}$, it is found that for all practical purposes, the versine on the chord between the tangent points is equal to half the perpendicular distance between the chord and the intersection of the tangents, i.e. in Fig. 67, $AM = \frac{1}{2}OM$.

Thus when the tangent points are fixed, all that is necessary, when N is more than $2\frac{1}{2}$, is to measure the distance OM and bisect it to obtain the point A. The remainder of the points on the curve can then be fixed as previously described.

If it is necessary to calculate the value of V when N is greater than $2\frac{1}{2}$ the rule is $V = \frac{L}{4N} = \frac{L^2}{2R}$.

It will be noticed that both the above methods of setting out a curve between two tangents depend on it being possible to measure the distance OM. Cases may be found in practice where this is not possible owing to obstructions.

The following method of obtaining the point A, when N is more than $2\frac{1}{2}$, avoids the necessity for the length OM being measured. The middle points J and K of the tangent legs must be found, and then the middle point of the line joining these is A, i.e. $JA = AK = \frac{1}{2}JK$.

A curve can also be set out direct from the tangent line for a short way in the following manner.

Calculate the versine ' V ' on a convenient chord length ' C '. Extend the tangent past the tangent point T, and mark on it points A, B, C, etc., so that TA, AB, BC are equal to $\frac{1}{2}C$. At A set up the offset at right angles to the tangent equal in length to V. This gives the first point on the curve.

The method of fixing the remainder of the points depends on the fact that *within certain limits* offsets to a curve from a tangent are very nearly proportional to the square of the distance of the offset from the tangent point.

As shewn in Fig. 68, therefore, the distance TB is twice the distance TA, and, therefore, the offset at B is 2^2, i.e. 4,

times the offset at A, i.e. is equal to 4V. Similarly the offset at C is equal to 9V.

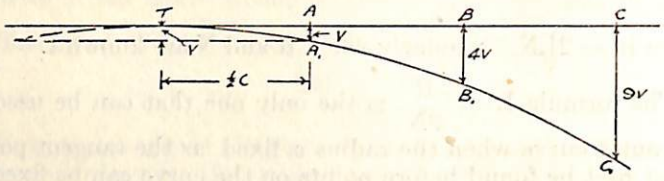


Fig. 68.

SHORT RAILS.

In the foregoing general considerations of track curvature, the fact that the two rails are of different radii makes no material difference, but in actual practice it is important to observe that they are really concentric arcs, of radii which differ by the distance between the centres of the rails, i.e., gauge + width of rail = $4' 11\frac{1}{4}'' = 4 \cdot 94$ feet.

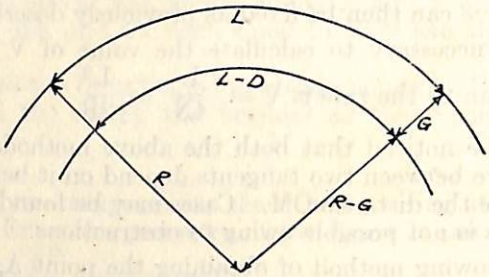


Fig. 69.

The outer rail will thus be longer than the inner rail and the lengths of these two rails will vary in proportion to their distances from the centre, i.e. their respective radii.

Thus if R in Fig. 69 is the radius of the outer rail and G is the distance between centres of rails, then the radius of the inner rail will be R — G, and if the length of the outer rail is L, and its excess of length over the inner rail be D, then the length of the inner rail will be L — D, and we have the relation :—

$$\frac{R}{R-G} = \frac{L}{L-D}$$

or $$L(R - G) = R(L - D)$$

$$LR - LG = LR - RD$$

$$LG = RD$$

and $$D = \frac{LG}{R}$$

The difference in length (D) for rails of a few standard lengths is—

$$\text{For 30 ft. Rails } D = \frac{4{\cdot}94 \times 12 \times 30}{\text{radius of curve in feet}} = \frac{1778}{R}$$

$$\text{For 45 ft. Rails } D = \frac{4{\cdot}94 \times 12 \times 45}{R} = \frac{2667}{R}$$

$$\text{For 60 ft. Rails } D = \frac{4{\cdot}94 \times 12 \times 60}{R} = \frac{3556}{R}$$

These expressions give the difference in length in inches.

If it is required to get the difference in lengths direct from the versine, a formula for this can be derived by substituting the relation of

$$R = \frac{\left(\frac{C}{2}\right)^2}{2V}$$

in the above formula in which the length of the rail becomes C the chord.

$$D = \frac{G.C.V.8}{C^2} \text{ or } = \frac{G.V.8}{C}$$

$$\text{For 30 ft. Rails } D = \frac{4{\cdot}94 \times V \times 8}{30} = \frac{4}{3}V \text{ nearly.}$$

$$\text{For 45 ft. Rails } D = \frac{4{\cdot}94 \times V \times 8}{45} = \frac{7}{8}V \text{ nearly.}$$

$$\text{For 60 ft. Rails } D = \frac{4{\cdot}94 \times V \times 8}{60} = \frac{2}{3}V \text{ nearly.}$$

It is not usual to provide short rails of odd lengths and the general practice is to shorten the rails by the distance between fishbolt holes so that when cut there is only one additional hole to be drilled.*

This distance in British standard track is $4\frac{1}{2}''$ and in order to know how many short rails are required in the whole curve we must first find out from the above formulæ the difference of length of each rail, multiply this by the number of rails in the curve and divide the result by $4\frac{1}{2}''$ (or 3″ on the Great Western Railway, *see* note below).

Example.—If for instance the curve is to consist of twenty-five rails each 45 ft. long and the radius is 20 chains then the difference in length of each rail is

$$\frac{2667}{66 \times 20} = 2{\cdot}02 \text{ inches.}$$

*On the Great Western Railway the special short rails used are 3″ shorter than the corresponding standard rails

The total difference of length of the outer and inner curves in the curve is thus $25 \times 2{\cdot}02 = 50\frac{1}{2}$ inches and the number of 'short' rails will be $\frac{50\frac{1}{2}}{4\frac{1}{2}} = 11$ nearly.

By spacing these short rails out at as nearly equal distances as is possible, any excessive lead of the joints can be avoided. In the above case the full length and short rails will have to be laid alternately for the inside rail.

In relaying an existing curve it is customary to avoid calculations by measuring out carefully the lengths of the new rails along the inside and outside rails, squaring across from the outside joints and allowing for a short rail to be inserted when the lead amounts to $2\frac{1}{4}''$. ($1\frac{1}{2}''$ on the Great Western Railway).

It should be noted that the makers of B.S. track are allowed a tolerance of $\frac{3}{16}''$ in cutting rails to length.

It is possible, therefore to find rails either $\frac{3}{16}''$ longer or $\frac{3}{16}''$ shorter than the standard length.

If opportunity occurs, the shorter rails should be kept for the inside of the curve, so as to reduce as far as possible the number of short rails required.

SUPERELEVATION.

It is a well known law of motion that if a body is moving in a straight line, it will continue to do so until acted upon by some other force.

In the case of the railway vehicle the force which diverts it along a curved path is provided by the pressure of the outside rail against the flange of the leading wheel.

This force is equal and opposite to the force which arises when a body is compelled to follow a circular path, while as we have seen above, its natural tendency is to continue in a straight path.

This force is called the centrifugal force and a simple experiment with a stone or small weight tied to a piece of string will illustrate its action.

When the end of the string is held in the hand and the stone whirled round, it is forced to follow a circular path, and the pull felt in the string is the reaction to the centrifugal force set up by the motion of the stone. If the string is suddenly released the stone will resume its straight path, or, as we say, fly off at a tangent.

If one could insert a spring or length of indiarubber cord in the string and experiment with different weights and different speeds of rotation one would find that the extension

of the spring varied in direct proportion to the mass of the stone, but varied directly as the square of the speed and inversely as the length of the string or radius. Thus the centrifugal force is equal to the mass multiplied by the square of the speed and divided by the radius.

In the case of a railway vehicle forced to move on a curved track the forces acting at its centre of gravity are (1) the centrifugal force acting outwards and (2) its weight acting downwards.

These forces are indicated graphically in Fig. 70A where X represents the centre of gravity of the locomotive, XC represents in direction and to scale the amount of the centrifugal force for a certain speed and radius of curve, and XW represents to the same scale, the weight of the locomotive.

If the parallelogram CXWR is completed, the diagonal XR will represent by its direction and length, the resultant of the forces XC and XW. It may be considered as the force which could replace those two or, by reversing its direction, the force which would exactly balance them.

This resultant force XR acts towards the outer rail, and this causes a greater load on the outer rail than on the inner.

Further, if the speed (V) is increased or the radius (R) decreased the centrifugal force will be greater, XC will be longer while XW remains the same and XR will get nearer and nearer to the outside rail.

When the conditions are such that the resultant passes through the point of contact of the wheel, with the rail there is no load on the inside rail and the vehicle is on the point of overturning.

Reference was made at the beginning of this section to the fact that the force necessary to divert the leading wheels of a rail vehicle from their desire to follow a straight path was provided by the resistance of the outside rail.

The question of the action of flanges against rails will be investigated later but it is fairly evident that on a curve with rails level across, conditions could be reached at moderate speeds which would occasion so much pressure between the flange and the rail as to force the wheel up over the rail, and become derailed.

Without knowing all the factors of the case (e.g. condition of rails and tyres, heights of centre of gravity, etc., etc.) it would not be possible to say which form of derailment would occur first. It may be observed, however, that while derailments due to overturning are rare, those caused by wheel climbing are fairly frequent.

The method adopted for reducing as far as possible the irregular stressing of the rails arising from the action of centrifugal forces, is to make the plane of the tops of the rails normal (at right angles) to the resultant of the centrifugal force and the weight.

This means that the outer rail is raised above the inner rail or that the track is canted. As the word 'cant' is sometimes used in connection with the inward tilt of rails, the word superelevation will be used throughout this section to describe the amount by which the outside rail is raised above the inside rail on a curve.

The method by which the superelevation is determined can be seen from Fig. 70B in which XC represents the centrifugal force, XW is the weight, K is the superelevation and B the distance between centres of rails.

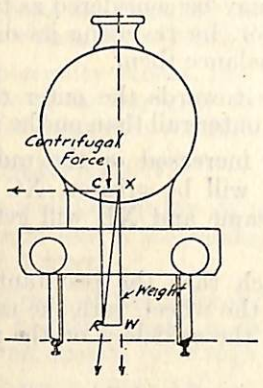


FIG. 70A.

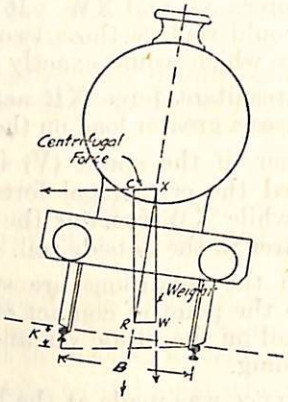


FIG. 70B.

From Fig. 70B it is seen that when XR is normal to the surface of the rails we have similar triangles in which

$$\frac{K}{B} = \frac{X\,C}{X\,W} \text{ or } K = \frac{B.W.v^2}{W.g.R.} = \frac{B\,v^2}{g\,R}$$

where v is the velocity, in feet per second, R is the radius in feet, and g, known as the 'acceleration due to gravity' has a value of 32 approximately.

Since the velocity 'v' is in feet per second and one mile per hour is 5,280 feet in 3,600 seconds, for v ft. per second we can write $\frac{5,280}{3,600}$ v m.p.h., and B is nearly 5 feet, hence, when K is in inches,

$$K = \frac{12 \times 5 \times \left(\frac{5280}{3600}v\right)^2}{32 \times R} = \frac{128\ v^2}{32\ R} \text{ approx.}$$

$$= \frac{4\ v^2}{R}$$

where v is in miles per hour and R is in feet, or

$$K = 0{\cdot}06\frac{v^2}{R}$$

where R is in chains.

It is important to note that the superelevation calculated in this way is applicable for a fixed speed. It cannot of course be varied to suit the different speeds at which trains pass along the track.

If we provide superelevation suitable for a speed of say, 40 m.p.h. and a train travels over the curve faster than 40 m.p.h., the stresses on the rails are again unequal and there is an excess of load on the outside rail. Similarly, if a train travels over the curve at a speed less than 40 m.p.h., there is an excess of load on the inside rail.

The determination of the amount of superelevation to be given must, therefore, be a compromise based generally on the higher average speeds and ignoring possible extremes of high or low speed.

The above method of balancing the forces set up by the motion of a train on a curve, is based upon the equalisation of the loads on the rails. It would be applicable for smooth (i.e. unflanged) wheels on a flat surface for it does not take into consideration the coning of the wheels or the reaction between the outside rail and the flange of the leading wheel.

There is considerable difficulty in determining the effect of these, for reasons which will be discussed later, but it will be sufficient at this stage to recognize that whatever the superelevation or radius or speed may be, the flange of the leading wheel bears against the high rail and that this lateral pressure must permit of a certain amount of reduction of the superelevation below the amount calculated by the above method, or putting it in another way, this pressure permits speeds in excess of that for which the superelevation was calculated.

It is a well-known fact that trains travel safely round curves at speeds considerably in excess of those calculated in this manner and it is generally accepted that some reduction of the theoretical superelevation can safely be employed.

There is, however, great divergence of opinion as to the amount of this reduction.

For the purpose of this section it is necessary to adopt, for use in examples, some definite reduction of the theoretical superelevation and without attempting to justify the procedure, the 'practical' superelevation is frequently taken to be three-quarters (75%) of the superelevation derived from the foregoing calculations, although on the various Railways the proportion varies between five-eighths and seven-eighths.

Using the value of threequarters, the formula, when the radius is in chains will thus become

$$K = 0{\cdot}045\,\frac{v^2}{R},$$

and when the radius is in feet,

$$K = \frac{3v^2}{R}.$$

These formulæ give the value of K in inches.

The amount of superelevation which can safely be put on a curve and properly maintained is about one-tenth of the gauge or 5½ inches with our standard; and although there are well-known cases in which higher amounts are in use, some special circumstances are required to justify superelevation beyond this limit.

When working to the limit in the attempt to allow for high speed on curves of small radius it must always be remembered that trains will at times be forced to run over them at speeds much below those for which the calculation is made.

In these circumstances there is an excess of load on the low rail and it is not inconceivable that if a light van with a large surface exposed to the wind were brought to a stand on such a curve, the wind pressure might be sufficient to overturn it.

It will readily be seen that as soon as a limit of superelevation is fixed, one is likely to be faced with conditions of curvature and speed which cannot be reconciled within that limit.

In such cases it is necessary to reduce the speed to conform to the maximum superelevation.

This limiting speed can be found at once by inserting the maximum superelevation in the formula, as in the following example where the superelevation is to be 5″ and the radius of the curve is 10 chains or 660 feet :—

$$5 = \frac{3\,v^2}{660}$$

$$v^2 = \frac{5 \times 660}{3} = 1100$$

$$v = \sqrt{1{,}100} = 33{\cdot}2 \text{ m.p.h.}$$

Since the superelevation for a given speed on any curve depends on the radius of the curve, and the versine on the curve depends on the radius and chord length, it is possible to determine the chord length on which the versine will be equal to the superelevation required for any given speed.

Thus, $V = \frac{\left(\frac{C}{2}\right)^2}{2R}$ and the theoretical K in feet $= \frac{4v^2}{12\,R}$

By equating these values of V and K, and eliminating R, it can be shewn that C = 1·63 v i.e. the chord length C in feet, on which the versine is equal to the theoretical superelevation required for a speed of v m.p.h. is 1·63 v.

Similarly the chord length in feet on which the versine is equal to the practical superelevation for a speed of v m.p.h. is 1.41 v.

If more exact values of B and g, then 5 ft. and 32 are used in the formula it is found that the value of C to give the theoretical supervlevation is 1·62 v. This value has been used in preparing the following table of chord lengths on which the versine of a curve will give the theoretical or practical superelevation required for the speed specified.

Thus, if it is known that the average speed of trains on a curve is 65 m.p.h., all that is necessary to find the practical superelevation required, is to measure the versine on a chord length of 91′ 8″. (*See* table).

Speed in miles per hour.	Theoretical superelevation. Chord = 1·62 v.	Practical superelevation. Chord = 1·41 v.
	feet ins.	feet ins.
70	113 5	98 9
65	105 4	91 8
60	97 3	84 7
55	89 1	77 6
50	81 0	70 6
46·8	—	66 0
45	72 11	63 5
*44	—	61 9
40·7	66 0	—
40	64 10	56 5
*38	61 9	—
35	56 9	49 4
30	48 7	42 4
25	40 6	35 3
20	32 5	28 3
15	24 4	21 2

* It will be observed that theoretical superelevation in inches equals the ‘ degree ’ of the curve for speeds of 38 m.p.h. and that the practical superelevation equals ‘ degree ’ for 44 m.p.h. (*See* p. 201)

TRANSITION CURVES.

From what has been said above concerning the forces acting when a train moves on a curved track it will be evident that the provision for balancing those forces, i.e. the superelevation, must be continuous throughout the whole length of the curve.

Where a circular curve joins directly on to a piece of straight track there is at the tangent point the condition that at one moment no superelevation is wanted and at the next the full superelevation appropriate to the curve is required.

If the alignment is to remain unaltered there exist the following alternatives :—

(*a*) that of attaining and running out the superelevation gradually on the straight so as to ensure the full superelevation on the curve.

(*b*) that of leaving the straights at their correct level and attaining and running out the superelevation on the ends of the curve.

(*c*) that of attaining and running out the superelevation partly on the straight and partly on the curves.

These alternatives are all bad both in theory and practice. (*See* Fig. 71).

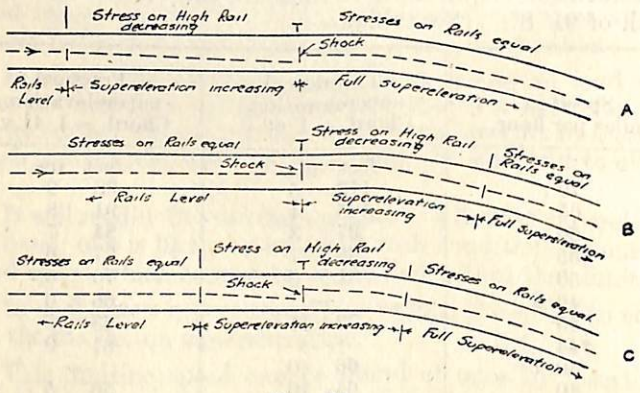


FIG. 71.

In (*a*) the weight of the train gradually becomes shifted to the inside rail while still on the straight and then suddenly thrown back to normal as the tangent point is reached.

Where the superelevation is considerable the shock of this sudden displacement may be serious and is in any case the cause of that irregular stressing of the engine springs which results in rolling and distortion of the track.

In (*b*) the centrifugal forces are unbalanced at the entrance to the curve as indicated, and the leading outside wheels of the vehicles have to bear the brunt. Even if the flanges were not forced up over the rail there would be excessive wear and uncomfortable travelling until the proper amount of superelevation was reached.

In (*c*) there is a combination of these faults with the same shock at the tangent point and conditions conducive to rolling, excessive wear and discomfort.

The only method of getting over these serious difficulties is to insert between the straight and the circular curve another curve in which the radius is gradually decreased from infinity to that of the circular curve. Similarly at the other end of the circular curve it is necessary to increase the radius until it becomes infinitely great or, in other words, a straight line. This also has the effect of gradually increasing the centrifugal force from zero on the straight to the full amount on the curve, instead of the sudden application where the curve is directly tangential to the straight.

Such a curve is called a transition curve or easement, and the curve usually employed in this country is the cubic parabola. In this curve the offsets from the straight increase in proportion to the cube of their distance from the point of origin and the radius at any point on the curve varies inversely as the distance of that point from the point of origin.

Such a parabola plotted with either eight, ten or twelve offsets is shown in Fig. 72.

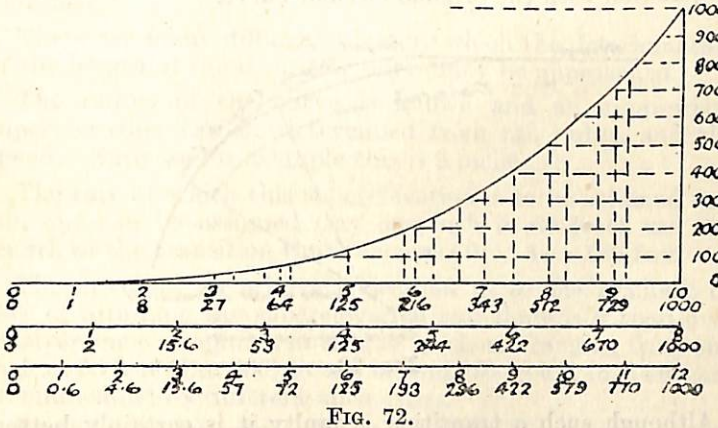


FIG. 72.

For convenience the offset at the end has been divided into thousandths, and where this offset is fixed in value, the method

of obtaining the offset at any point is by proportion. For instance, if the end offset is 10 ft., and there are 8 points on the curve, the offset at point 5 is obtained by dividing the offset of 10 ft. by 1,000, and multiplying by the figure under the figure 5 in the line with 8 divisions, in this case 244,

$$\text{i.e. offset at } 5 = \frac{10 \times 244}{1{,}000} = 2' \, 5\tfrac{1}{4}''$$

The point of origin where the curve joins the tangent is O and it should be noticed that the offsets at points marked 4, for instance, are 2^3 or eight times the offsets at points marked 2 and that offsets at points marked 9 are 3^3 or 27 times the offsets at points marked 3.

In other words the offsets vary as the cube of their distance from O the point of origin.

Similarly the radius of the curve at 4 is half the radius of the curve at 2 ; at 6 it is $\frac{1}{3}$ of the radius at 2 and so on.

A transition curve such as this cannot be inserted between an existing straight and an existing circular curve. Either the straight or the curve has to be displaced or ' shifted ' to a position parallel to its original alignment.

Attempts to effect an easement of the junction of a circular curve and tangent without a ' shift ' must necessarily lead to a sharpening of the curve.

The arrangement is commonly known as the platelayer's transition, and it will be seen from Fig. 73 that the easing at the tangent point has led to a sharpening of the curve before its junction with the original circular curve.

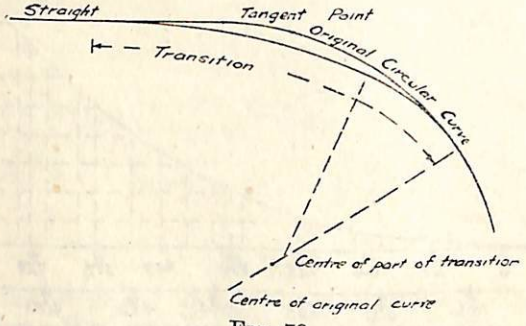


FIG. 73.

Although such a transition is faulty it is certainly better than no transition at all and enables the superelevation to be attained without any of the shock which is bound to arise when the circular curve starts directly from the straight.

The proper arrangement of a transition curve is shown in Fig. 74. The original circular curve TC is tangential to the straight at T. The curve is shifted to ZY, and TZ is the amount of shift.

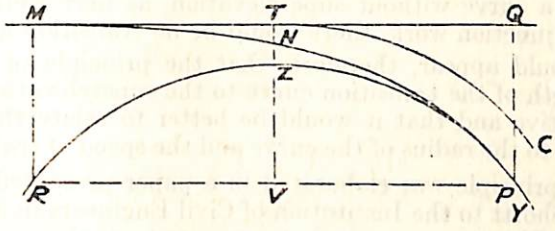


FIG. 74.

The transition curve MNP bisects the ' shift ' TZ at N.

The total length of the transition curve (measured along the tangent) is MQ and MT is equal to TQ.

By reference again to Fig. 74 it will be seen that the offset QP at the end of the transition will be eight times the offset at TN. But this offset TN is half the ' shift ' (S), so that QP is equal to 4 S.

By drawing the chord from P to R parallel to the tangent it is seen that the versine VZ plus TZ (the shift) is equal to QP or 4 $\times$ shift.

The versine is, therefore, equal to 3 S and it will be apparent that as soon as the length of the transition curve is decided all the information required to set out the transition can be obtained.

There are many different ways by which the determination of the length of the transition curve may be approached.

The radius of the curve is known and an appropriate superelevation can be determined from the radius and the speed. Suppose for example this is 3 inches.

The rate at which this superelevation is to be attained and run out can be assumed (say one inch in 60 feet) and the length of the transition thus becomes 60 $\times$ 3 = 180 feet.

This involves an arbitrary decision as to the gradient or rate of attaining the superelevation and there is a good deal of divergence of opinion in this, as gradients ranging from one inch in 30 feet (1 in 360) to one inch in 120 feet (1 in 1,440) are recommended by different authorities.

Practical railwaymen will know that the circumstances which permit of the use of just the superelevation required and a free hand as regards the lengths of transitions are indeed rare.

Considering the conditions, which are not infrequent, in which it is necessary to adopt a superelevation which is much less than is desired, the method described on p. 221 would then shorten the transition proportionately and in the extreme case of a curve without superelevation, as may well be met with in junction work, there would be no transition at all.

It would appear, therefore, that the principle of relating the length of the transition curve to the superelevation alone, is defective and that it would be better to relate the length directly to the radius of the curve and the speed of trains on it.

This principle was elaborated in a paper presented by Mr. W. H. Shortt to the Institution of Civil Engineers in January, 1909.* This paper and that presented at the same time by Mr. J. W. Spiller should be read by those who wish to go more deeply into the matter.

Mr. Shortt bases his calculations on a fixed rate of gain or loss of radial acceleration (i.e., acceleration to or from the centre of the circle which is proportional to the centrifugal force) and found by experiment that 1 foot per second per second in every second was as much as would pass unnoticed.

The rate of change of acceleration in moving along the transition is given by dividing the radial acceleration $\left(\frac{v^2}{r}\right)$ by the time taken $\left(\frac{l}{v}\right)$

$$\text{i.e.} \quad \frac{v^2}{r} \div \frac{l}{v} = \frac{v^3}{lr}$$

and accepting the limiting rate as 1 foot per second per second in a second then

$$\text{length of transition} = \frac{v^3}{r}$$

Mr. Shortt also stipulated as the result of numerous experiments that the maximum speed regularly attained by trains on curves was about $11 \cdot 13 \sqrt{R}$ where speed is in m.p.h. and R is in chains.

Substituting this value in the above formula and converting v in feet per second to m.p.h. and r radius in feet to R radius in chains we have

$$L = \sqrt{R}$$

This is applicable to curves of less than 54·3 chains radius. For high speeds on flatter curves a simpler form can be obtained by substituting the speed in the formula

$$\frac{v^3}{r} = 1$$

* Proceedings Inst. C.E., Vol. CLXXVI. 1908-9. Pt. II.

Referring again to Fig. 74 in which it was already seen that the chord RP is equal to the length of the transition curve, and that the versine ZV is equal to 3 x shift, by substituting these new values in the formula established for the versine

$$V = \frac{\left(\frac{C}{2}\right)^2}{2R}$$

we have

$$3s = \frac{\left(\frac{l^2}{2}\right)}{2R} = \frac{l^2}{8R}$$

whence the shift 's' $= \frac{l^2}{24R}$

If we are adopting Mr. Shortt's method in which

$$L = \sqrt{R}$$

then the shift in chains $= \frac{\sqrt{R} \times \sqrt{R}}{24R} = \frac{1}{24}$

$= \frac{66}{24}$ ft. $= 2$ feet 9 inches.

which is thus constant for all transitions.

It will be interesting probably at this stage to make a comparison between the results obtained by applying these two methods to an actual example.

Take a curve of 25 chains radius with a speed of 40 m.p.h.

The practical superelevation is

$$K = 0{\cdot}045 \frac{V^2}{R}$$

$$= \frac{{\cdot}045 \times 40 \times 40}{25} = 2{\cdot}88 \text{ inches}$$

$=$ say 3 inches.

If this superelevation is to be attained at the rate of 1 inch per chain then the length of the transition will be 3 chains $= 198$ feet and the shift will be :—

$$\text{shift in feet} = \frac{l^2}{24R} = \frac{3 \times 3 \times 66 \times 66}{24 \times 25 \times 66}$$

$$= \frac{198}{200}$$

$=$ say 1 foot.

Using Mr. Shortt's method the length of the transition will be :—

$$L = \sqrt{R}$$
$$= \sqrt{25} = 5 \text{ chains}$$

and the shift will be 2′ 9″ as shown on p. 223.

In setting out a transition or easement of an existing curve the tangent point (T) is first defined and the length of the transition curve pegged out as at M and Q in Fig. 74, i.e. half on each side of T.

The ' shift ' TZ is then pegged out and a peg midway between T and Z gives N a point halfway along the curve.

The offset QP at the end of the curve is four times the ' shift ' or eight times the offset TN.

The length of the curve will decide the number of intermediate offsets required and from the figures given on Fig. 72 we can work out the distances for 4, 5, 6, 8, 10 or 12 offsets, the last three by using all the figures given, and the first three by omitting the alternate offsets.

It is important to remember that any transition is better than none. Cases will frequently occur in which it is not possible to use the shift required or the length of transition desirable. It should be noted that the same effect is obtained by ' shifting ' the straight as by ' shifting ' the curve, and in the event of movement of the curve being restricted say by permanent structures such as bridge abutments it may still be possible to put in a transition by shifting the tangent.

Where two circular curves reverse directly without any length of straight in between, the shock felt at the reversal is even more than that felt at the entry to a circular curve tangential to a straight.

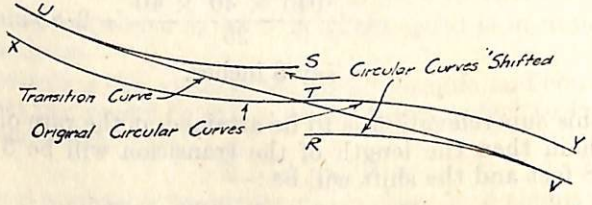


FIG. 75.

Thus in Fig. 75 two circular curves XT and TY are in opposite directions and are tangential at T. For a vehicle travelling on the curve XT the centrifugal force is towards

the outside of the curve until it reaches T where it is suddenly reversed when the vehicle gets on to the curve TY. A transition curve is therefore most necessary between two such curves. There are a number of ways in which a transition curve can be inserted between two reverse curves. For instance one or the other of the curves may be 'shifted', or as shewn in Fig. 75 both curves may be shifted to US and RV, and a transition curve UTV inserted. It is not necessary for the tansition curve to pass through T however. Probably the simplest way of inserting a transition between two existing reverse curves is by an adjustment of the versines (*See* p. 98).

In the case of a compound curve such as shewn in Fig. 62B, a transition curve is generally required between the parts of the curve which have different radii, unless the difference in radii is not more than 15%. The simplest way of introducing a transition between two curves of different radii curving in the same direction is by adjustment of the versines. (*See* p. 98).

MOVEMENT OF VEHICLES ON CURVES.

The movement of a train of railway vehicles or of only one vehicle on a curve introduces many very complex problems.

There are for instance wheels of many different sizes, tyres of different stages of wear, and vehicles of various wheel bases or distance between axles. The amount of 'play' in the axle boxes is also subject to considerable variation.

In recent years a great improvement has been made in the reduction of the length of rigid wheel bases of passenger vehicles by the substitution of bogie trucks. Steam locomotives are now generally the vehicles with the longest rigid wheel bases, but it is usual to thin out or remove altogether the flanges of the middle wheels where the total wheel base is long.

When a bogie truck or any vehicle with two parallel axles is on the straight it can be assumed that the flanges are both clear of the rails and central between them as in Fig. 76.

FIG. 76.

When the tangent point is passed the truck continues in a straight line until the flange of the leading outside wheel rubs against the side of the rail, as in Fig. 77. It continues to bear against the rail for the whole length of the curve, and is therefore running on a tread which is slightly larger in diameter than that of the inside leading wheel, owing to the coning of the wheels.

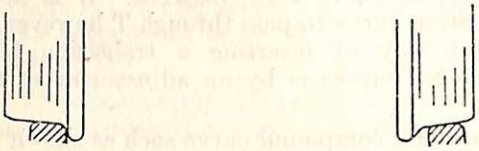


FIG. 77.

If this axle could adjust itself to be always radial to the curve, and if the effect of the coning exactly compensated for the difference in length of the inside and outside rails, the axle would run smoothly round the curve and there would be no tendency to slip.

Actually, however, neither of these conditions can be realised and slipping between the tyre and rail has to take place.

In making up the difference in length of the rails, the inside wheel must slide backwards or the outside wheel must slide forwards along the rail. It is possible also that both wheels may slip, but it is fairly certain that if one starts to slip, it will continue to do so.

In addition to this slipping along the rail there must be slipping across the rail in keeping the front axle always at right angles to the line of motion.

The flanges of the wheels of the rear axle generally run clear of the rails, and the axle is radial to the curve. *See* Fig. 78.

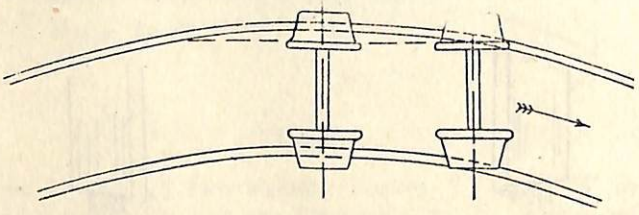


FIG. 78.

If, however, the radius of the curve is so small, or the wheelbase is so long, that the conditions indicated in Fig. 79 are reached, i.e., the versine on a chord of twice the wheel base is equal to the total 'play' between flanges and rails, then the flange of the inner wheel is rubbing the rail.

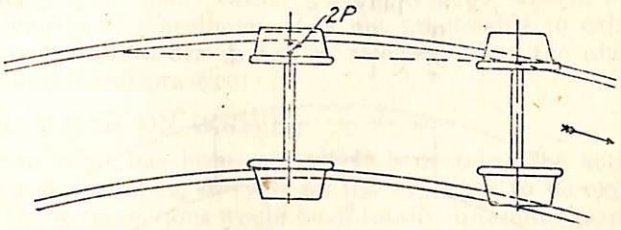


FIG. 79.

This radius may be calculated as follows: Suppose the distance between axles is 9 feet. Then the half chord is very nearly 9 feet plus the length of half the flange below the rail top.

From Fig. 80 we see that this length can be obtained from the ordinary versine formula

$$V = \frac{\left(\frac{C}{2}\right)^2}{2R} = \frac{C^2}{8R}$$

$$\text{whence } C = \sqrt{8\ V.R.}$$

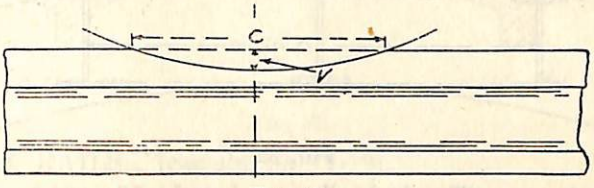


FIG. 80.

V in this case is half the depth of the flange, say $\frac{1}{2}''$ and R = radius of wheel at half the flange depth, say 20″. Then C or the length of the piece of the flange below the rail head

$$= \sqrt{8 \times \tfrac{1}{2} \times 20} = \sqrt{80} = \text{approx. } 9''.$$

The true half chord is this 9′ $4\frac{1}{2}''$ = 9·375 feet and if the 'play' for each flange is $\frac{1}{2}''$ then the versine 2P = 1″ or ·083 feet.

The radius in feet $= \frac{9 \cdot 375^2}{2 \times \cdot 083}$ = 530 feet nearly, or 8 chains.

Under this conditions wear of the side of the head of the inside rail would begin.

When the conditions shown in Fig. 81 are reached, the curve is of the minimum radius to accommodate the truck.

For practical purposes AD = wheelbase and DC = flange length, hence,

$$R = \frac{\text{wheel base} \times \text{flange length}}{2 \times \text{'play'}}, \text{ since } R = \frac{AD \times DC}{2 \times DB}$$

$$= \frac{9' \times 9''}{2 \times 1''} = 9 \times \tfrac{3}{4} \times 6 = 40 \text{ feet.}$$

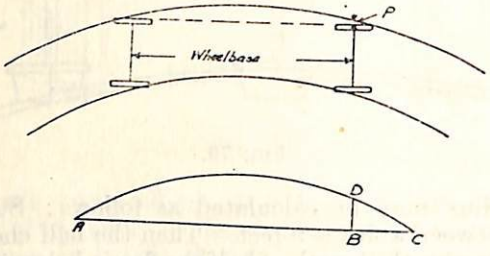


FIG. 81.

In the case of six wheeled vehicles the middle axle is usually given lateral 'play' or the flanges are thinned off. The limiting conditions are thus shown in Fig. 82, where V = total clearance plus extra lateral 'play' (say 1″).

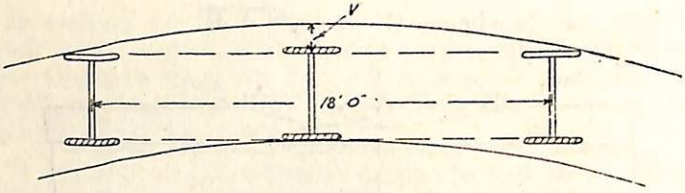


FIG. 82.

$$R = \left(\frac{\text{Total wheelbase} + \text{length of flange}}{2}\right)^2 \div 2V$$

$$= \left(\frac{18'\ 9''}{2}\right)^2 \div 2(\tfrac{1}{2}'' + 1'')$$

$$= 9{\cdot}375^2 \div 3'' = \frac{87{\cdot}89}{0{\cdot}25} = 351\tfrac{1}{2} \text{ ft.}$$

It should be observed that all the clearances given in the above examples are liable to substantial variations in consequence of wear both of flange and tyres, and that under these conditions the passage of vehicles would be easier.

From the above it will be seen that any widening of the gauge has the effect of increasing the play and so providing an easier passage for the vehicle.

It is not usually necessary to widen gauge on curves over 10 to 12 chains radius.

Between 5 and 10 chains radius the gauge may be widened $\frac{1}{4}''$ and those of radius below 5 chains $\frac{1}{2}''$.

Owing to the many varied types of vehicles, sizes of wheels, and lengths of wheelbases, it is not practicable to calculate what advantages are gained in this way, but the above is well-established practice.

RAIL WEAR ON CURVES.

From what has been said above concerning the action of flanges and slipping of tyres on the rails it is to be expected that the worn sections would be of totally different character.

This is in fact the case. The outer rail shows principally the result of grinding on the inside nosing of the rail head and in extreme cases this is worn right down to the shape of the flange.

There is normally very little indication of spreading of the head.

The inside rail, however, is normally spread (as the result of transverse slipping) and shows no sign of flange grinding. Fig. 83 shews the type of rail wear on curves.

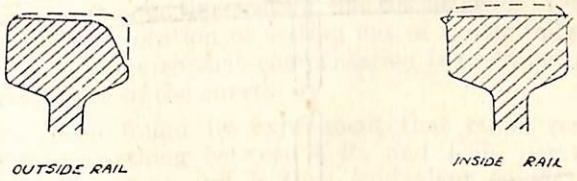


FIG. 83.

CHECK RAILS. (*See also pp.* 17-19).

The pressure of the flange of the leading wheel against the outside rail leads not only to excessive wear but also to a risk of the tyre climbing up over the rail.

In order to minimise this risk a check rail is fixed inside the low rail and parallel to it. The distance between the two rails is called the flange way and is determined by the thickness of the flange of the tyre and the total amount of side movement or ' play ' between the flanges and the rails.

The flange being curved throughout there may be a little difference of opinion as to where its thickness is to be measured, but for this purpose the flange (of new section) is assumed to be tight up against the outside rail. The thickness is then the distance between the gauge side of the rail and the back of the wheel, say $1\frac{1}{8}''$.

The space between the backs of the wheels is 4′ $5\frac{5}{8}$″ and the back of the inside wheel will thus be 4′ $5\frac{5}{8}$″ + $1\frac{1}{8}$″ = 4′ $6\frac{3}{4}$″ from the gauge side of the outside rail as shewn in Fig. 7, p. 18. This distance (4′ $6\frac{3}{4}$″) is called the check rail gauge, and the flangeway will be 4′ $8\frac{1}{2}$″ — 4′ $6\frac{3}{4}$″ or $1\frac{3}{4}$″.

When a check rail is fitted with this flangeway the back of the inside wheel will be rubbing against the check rail when the tyre (of new section) of the outside wheel is rubbing against the outside rail.

As the tyre is subject to wear all the time that it is running, and as the back of the wheel only wears when it comes against a check rail, it is evident that it must frequently occur that the check rail is taking the wear and relieving the outside rail. When this occurs the grinding of the wheel against the check rail will soon widen the flangeway, and the check rail will fail to serve any useful purpose.

In order to reduce the wear of the check rail, certain railways raise it above the level of the running rail so that a larger surface is in contact with the back of the wheel.

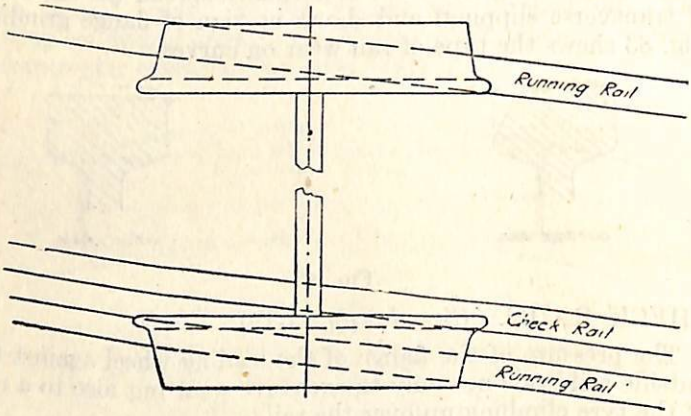


FIG. 84.

It should be remembered though that the wheel is not tangential to the curve but at an angle across it. (*See* Fig. 84).

By raising the rail, the length of flange beneath it is increased, and the effect of the wheel being at an angle to the rail is to bring the flange into contact with the rail earlier, which has the same effect as reducing the flangeway.

It is stipulated by the Ministry of Transport that continuous check rails must be provided on all curves of 10 chains radius or less on passenger lines, but on lines where speed is high

and especially on electrified lines it has been found profitable to provide check rails on curves of much larger radius.

Check rails are usually fixed *vertically* in special chairs. The end of the check rail should be splayed out so that the entrance to the flangeway is double the normal width, and special chairs are required to hold the splayed ends of the rail. (*See* p. 18).

When the gauge is widened (*see* p. 228) the flangeway should be correspondingly widened to maintain the 4′ $6\frac{3}{4}$″ check rail gauge. Special chairs are used to provide this wider flangeway.

It should be observed that the stress on the check rail is across the head, or tending to turn the rail inwards. This is resisted only by the keys, and these should be frequently examined so that any which show signs of crushing may be replaced without delay.

EFFECT OF CURVES ON TRAIN RUNNING.

It will be appreciated that the slipping and grinding of tyres and rails referred to above adds resistance to the passage of a train.

The permanent way man is concerned chiefly with the repair of the damage thus caused, but the surveyor or engineer occupied in the location or setting out of a new railway has to lay out his line so that compensation is provided for this extra resistance of the curves.

It has been found by experiment that curve resistance amounts to anything between $\frac{1}{2}$ lb. and 1 lb. per ton per degree of curvature and is thus equivalent to an adverse gradient of between 0·025 per cent. and 0·05 per cent. per degree of curvature.

It is customary to make an allowance of 0·04 per cent. for every degree of curvature, and this allowance must be applied to all curves which occur on the ruling gradient, i.e. the steepest gradient on a particular route.

By this means the resistance of curve plus resistance of gradient is kept within the limit stipulated by the ruling gradient. For example, if a railway is to be built with a ruling gradient of 1% (1 in 100) and there is a curve of 5° ($17\frac{1}{3}$ chains) in question, the resistance due to curvature is equivalent to an adverse gradient of

$$5 \times 0{\cdot}04 = 0{\cdot}2\%$$

and the gradient through the curve must, therefore be reduced to 0·8% (1 in 125) so that the stipulated maximum resistance should not be exceeded.

CHAPTER VIII.

SETTING OUT POINT AND CROSSING WORK BY USE OF STRING LINES.

As has already been explained in Chapter III, point and crossing work consists of three units, in various combinations, together with the necessary closure rails. These units are (1) the switch, (2) the common or vee crossing, and (3) the diamond, obtuse, or K crossing.

In order to set out point and crossing work on the ground, it is necessary to know the distances or leads between these units. The positions of the various units can then be marked on the ground by measuring out the leads along the appropriate rails.

The leads may be obtained by one of the three following methods :—

(1) by setting out with string lines.

(2) by calculation, using formulæ based on unit angles of switches and crossings, or

(3) by trigonometrical calculation.

Method (1) is dealt with in this Chapter, and Method (2) in the two following Chapters. Method (3) is not dealt with in this book.

The method of setting out point and crossing work by string line, is applicable where the rails joining the various units of the turnouts are either straight, or curved to a uniform radius (i.e. are parts of circular curves). It is not applicable to cases where the curves of the turnout are transition curves (i.e. of varying radius), although it is a useful method for setting out turnouts or junctions when the main line is curved either to a circular or a transition curve.

In Chapter VII on " Curves " certain mathematical relations between the parts of a curve illustrated in Fig. 85 were arrived

at, and the method under consideration depends on the practical application of these. They are listed below for reference :—

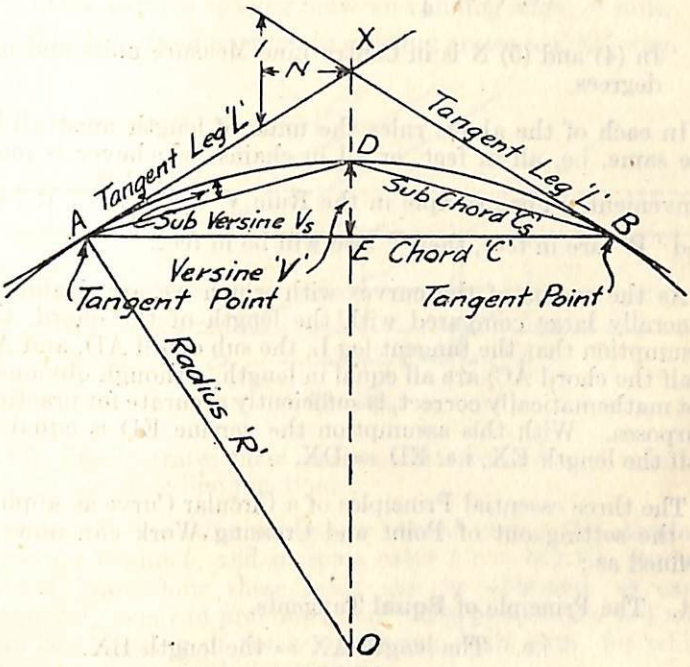


FIG. 85.

In Fig. 85 :—

(1) The tangent AX, is equal in length to the tangent BX.

(2) Given the chord C and the radius R,

$$\text{the versine } V = \frac{(\frac{1}{2}\,C)^2}{2R}$$

(3) Given the chord C and the versine V,

$$\text{the radius } R = \frac{(\frac{1}{2}\,C)^2}{2V}$$

(4) Given the tangent length L, and the angle of intersection of the tangents N

$$\text{the radius } R = 2LN.$$

(5) Given the radius R, and the angle of intersection of the tangents N

$$\text{the tangent length } L = \frac{R}{2N}$$

(6) The versines V_s on the sub chords AD, and DB, are equal to one quarter of the Versine V on the chord AB,

$$\text{i.e. } V_s = \frac{V}{4}$$

In (4) and (5) N is in Centre Line Measure units and not degrees.

In each of the above rules the units of length must all be the same, i.e. all in feet, or all in chains, whichever is most convenient. For example in the Rule $V = \frac{(\frac{1}{2} C)^2}{2R}$, if 'C' and 'R' are in feet, then V also will be in feet.

As the radius of the curves with which we are dealing is generally large compared with the length of the chord, the assumption that the tangent leg L, the sub chord AD, and AE (half the chord AC) are all equal in length, although obviously not mathematically correct, is sufficiently accurate for practical purposes. With this assumption the versine ED is equal to half the length EX, i.e. ED = DX.

The three essential Principles of a Circular Curve as applied to the setting out of Point and Crossing Work can now be defined as :—

1st. The Principle of **Equal** Tangents.

i.e. The length AX = the length BX.

2nd. The Principle of **Halving** the distance between the intersection of the tangents and the centre of the chord.

i.e. The length ED = the length DX.

3rd. The Principle of **Quartering** the versine on the full chord to obtain the versine on the sub chord.

$$\text{i.e. } V_s = \frac{V}{4}$$

It will be noticed that the above three principles are shewn in a definite sequence, this being done with a view to making them easy to memorise as the EQUAL, HALVING, and QUARTERING principles.

POINT AND CROSSING WORK WITH PARALLEL TRACKS.

All point and crossing work with parallel tracks can be divided into sections as follows :—

(*a*) The turnout lead from tip of switch to the common crossing.

(*b*) The lead from crossing to crossing across the 6′ 5½″ or other parallel spacing between running edges of rails.

(*c*) The lead from crossing to crossing across a 4′ 8½″ way.

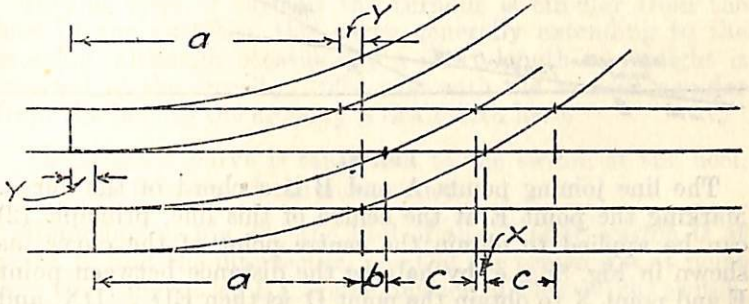


FIG. 86.

Fig. 86 illustrates these sections, lettered *a*, *b*, and *c*, in the case of a double line junction.

Generally speaking tables are issued giving the standard leads for *a* and *b*, and in some cases for *c*, but the student should know how these leads can be obtained, as cases frequently occur in practice where old type switches and non-standard spacing of tracks are being dealt with, for which no tables are generally available.

TRACK CROSSING 4′ 8½″ way.*

The most simple case to shew the application of the three principles previously referred to is Section '*c*' in Fig. 86. There are two crossings 1 in N and 1 in M on opposite rails of the track, and these have to be connected by a circular curve. The crossings are shewn at 'A' and 'B' in Fig. 87. The circular curve has to be tangential to the crossings at the intersection or 'fine' points of the crossings. Therefore one of the tangent legs to the curve cuts one rail at A making an angle of 1 in N with the rail, and the other tangent cuts the opposite rail at B at an angle of 1 in M. These tangents intersect at the point X, and by principle (1)—

* Throughout this section dimensions are given to the gauge faces or running edges of the rails, and the string lines referred to herein accordingly represent running edges. The same principles would apply, subject to suitable alteration of dimensions, if, as is the practice in some parts of the country, the outer edges of the rails were being adopted for setting out (i.e. with string lines 5′ 2″ apart).

the tangent leg AX = the tangent leg BX.

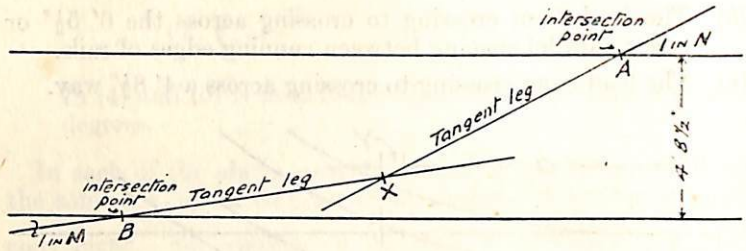


FIG. 87.

The line joining points A and B is a chord of the curve. Marking the point E at the centre of this line, principle (2) can be applied to obtain the centre point of the curve, as shewn in Fig. 88, i.e. by halving the distance between point E and point X to obtain the point D, as then ED = DX, and by principle (2), ED is a versine of the curve.

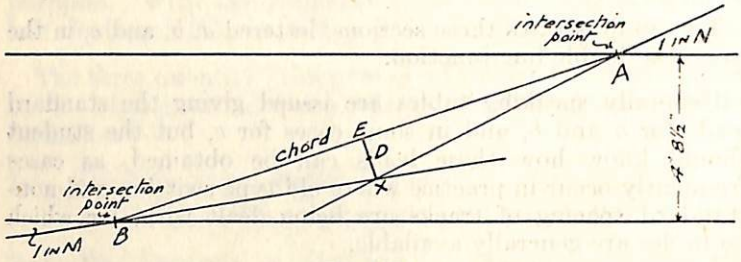


FIG. 88.

By joining points A and B to D, the sub-chords AD and BD are obtained (*see* Fig. 89). By principle (3) the versines at the centre of the sub-chords are equal to one quarter of the versine V on the chord AB, i.e. $V_s = \frac{ED}{4}$

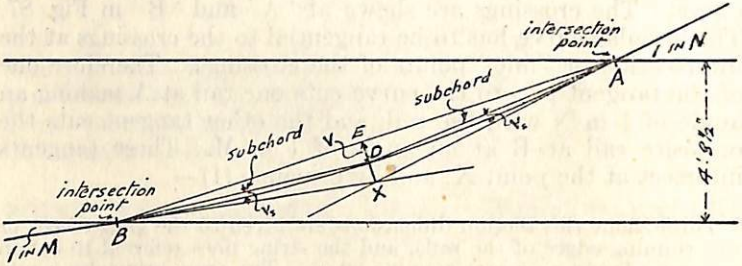


FIG. 89.

The circular curve passes through the three points on the arc as shewn.

TURNOUT LEAD.

The principles set out above are applicable to turnouts with straight type or British Standard switches.

(1) Turnout with straight switches*.

In this type of turnout the turnout is circular from the heel of the switches, this curve generally extending to the crossing, although occasionally a short length of straight is inserted at the crossing. The case with the turnout circular from the heel to the crossing is dealt with here.

The turnout curve is tangential to the switch at the heel, and to the crossing at the intersection.

Referring to Fig. 90, the heel of the straight switch is at point B, and the intersection point of the crossing is at point A. One tangent leg BX is an extension of the straight switch, and the other is the line AX passing through the fine point of the crossing A, at an angle of 1 in N with the running rail.

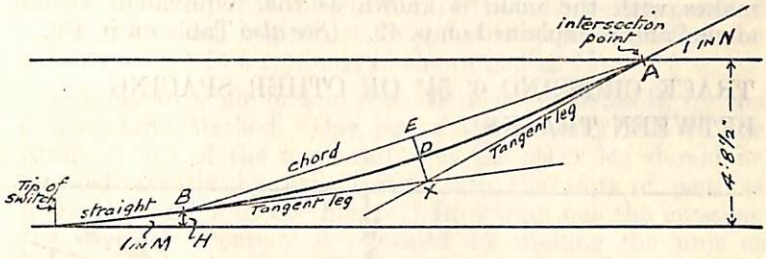


FIG. 90.

As in the previous example it will be seen that the tangent legs AX and BX are equal, and the versing ED is equal to one half of EX. Also the sub versines on the sub-chords AD and BD, are each equal to one quarter of ED.

(2) Turnout with Curved Type Switches.

In this type of turnout, the turnout curve is tangential to the crossing, and to the switch curve at the switch heel, *see* Fig. 91.

This means that the turnout curve is tangential to the tangent to the switch curve at the heel, as shewn in Fig. 91.

* For details of straight type switches, *see* p. 45.

As before AX is equal to BX, where A is the intersection point of the crossing, and B the heel of the switch, and the versine ED of the turnout curve is equal to one half of EX.

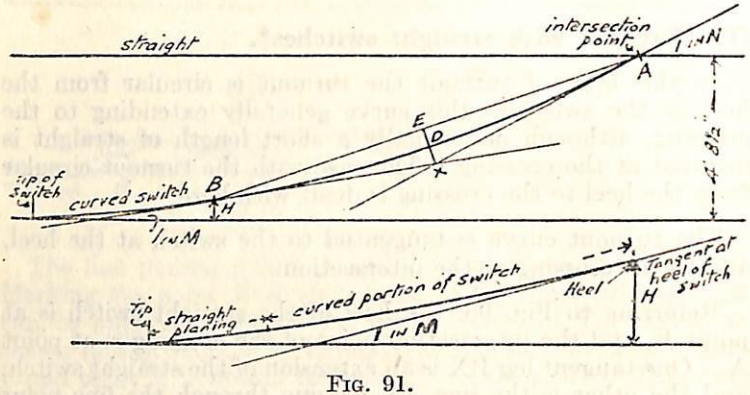


Fig. 91.

The angle that the tangent to the switch curve at the heel makes with the main is known as the 'equivalent switch angle' and is explained on p. 49. (*See also* Table on p. 45).

TRACK CROSSING 6′ 5½″ OR OTHER SPACING BETWEEN TRACKS.

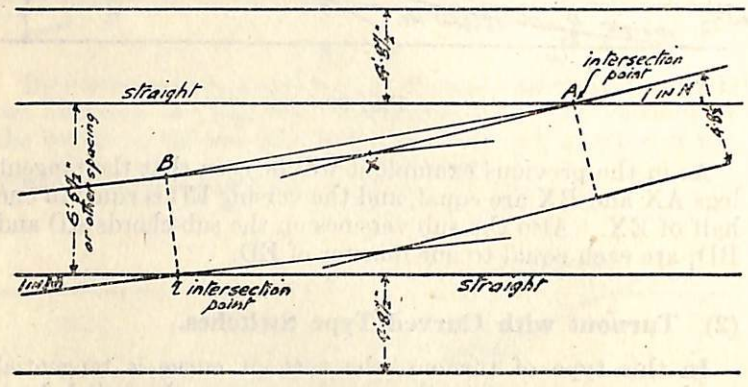


Fig. 92.

As will be seen from Fig. 92 the two crossings are on the opposite rails of the turnout, and therefore the tangent leg BX must be set up parallel to, and at a distance of 4′ 8½″ from, the crossing 1 in M. The tangent point B is square opposite

to the intersection point of the crossing. The method of setting out the curve between A and B tangential to the crossings is the same as in the previous examples.

EXAMPLE OF SETTING OUT BY STRING LINE ON THE GROUND.

Lead across 4′ 8½″ way. (Section (*c*) Fig. 86).

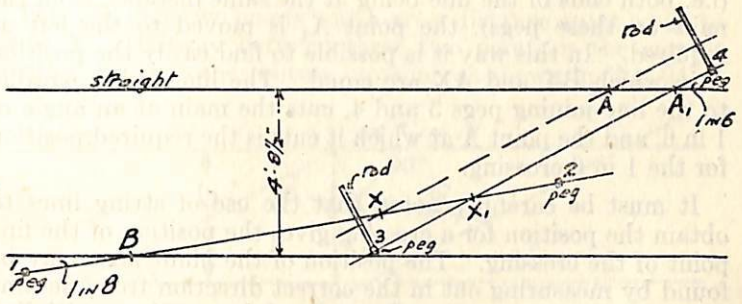


FIG. 93.

It is assumed that the position of the intersection point of a 1 in 8 crossing is given at B, and it is required to find the position of a 1 in 6 crossing, as shewn in Fig. 93.

Set out an angle of 1 in 8 to the main at point B, by the Centre Line Method. One leg of the crossing will be the running face of the main rail, and the other leg should be marked exactly by nails driven into the tops of pegs as marked 1 and 2 in the Figure. In setting out the crossing, the greatest accuracy is obtained by making the unit as large as possible, the unit of one yard generally giving the best results. For the 1 in 8 crossing 3′ in 24′ (i.e. 1 yard in 8 yards) should be used, and for the 1 in 6 crossing 3′ in 18′ (i.e. 1 yard in 6 yards).

Assume a position, say at A_1, for the 1 in 6 crossing, and set out the angle of this crossing as described above, by nails in the tops of pegs 3 and 4. The tops of pegs 1, 2, 3 and 4 should be as nearly as possible at the same level. One string line should be fixed to the nails on pegs 1 and 2, and the other on pegs 3 and 4, the lines being pulled as tight as possible, for which reason a strong, but fairly thin, line should be used.

Two lines are thus obtained intersecting at X_1.

By the first principle the two tangent legs should be equal, i.e. BX_1 should equal A_1X_1. From the figure it will be seen that this condition is not fulfilled, BX_1, being considerably longer than A_1X_1. Point A_1 has therefore to be moved to

the left. In order to save the trouble of driving in further pegs to set out the 1 in 6 crossing for other trials to find the correct position, the following method should be adopted. Fix two rods of convenient length, marked in inches and fractions of an inch, to pegs 3 and 4, and at right angles to the line joining them. By setting up a line, as shewn dotted and keeping it parallel to the line between pegs 3 and 4 (i.e. both ends of the line being at the same distance from the nails on these pegs), the point A_1 is moved to the left as required. In this way it is possible to find easily the position A in which BX and AX are equal. The line, being parallel to the line joining pegs 3 and 4, cuts the main at an angle of 1 in 6, and the point A at which it cuts is the required position for the 1 in 6 crossing.

It must be carefully noted that the use of string lines to obtain the position for a crossing gives the position of the fine point of the crossing. The position of the blunt nose may be found by measuring out in the correct direction from the fine point the distance equal to the angle of the crossing multiplied by the width of the crossing nose as described on p. 255.

The method of finding the position of crossings for section *c* can be adapted to find the positions for section *b*, and the method will be clear from Figs. 92 and 93.

Taking the position of the 1 in M crossing as fixed, the angle of 1 in M is set out. The tangent leg BX must be then set out parallel to this and at a distance of 4′ 8½″ therefrom. The tangent point B is obtained by squaring across from the fine point of the 1 in M crossing. As before a position must be assumed for the 1 in N crossing. The 1 in N crossing is then set up, and if the tangent legs so obtained are not equal, the 1 in N crossing must be moved until this condition is satisfied.

LEAD OF OBTUSE CROSSINGS TO OBTAIN TRUE GAUGE.

In order to obtain correct gauge at diamond crossings, it is necessary to fix the two crossings in their correct positions. By reference to Fig. 94 it will be seen that the crossing on the six-foot rail leads the crossing on the cess rail by the distance 'X'. This distance is obtained by dividing the gauge of the track by twice the angle of the diamond crossing

$$\text{i.e. } X = \frac{G}{2N}$$

Thus for a 1 in 8 diamond crossing

$$X = \frac{4' \, 8\frac{1}{2}''}{2 \times 8} = 3\tfrac{17}{32}'' \; (3\tfrac{1}{2}'' \text{ is usually given in tables of this dimension}).$$

The correct position of the opposite crossing when the position of one is given on the ground can also be obtained as follows :—

Square off both rails of the obtuse crossing of which the position is known at the intersection point (or off the main rail, and the string representing the crossing rail), on to the opposite rail.

This will give two points which are a distance apart equal to twice X. Halfway between these two points is the correct position for the other obtuse crossing, as shewn in Fig. 94.

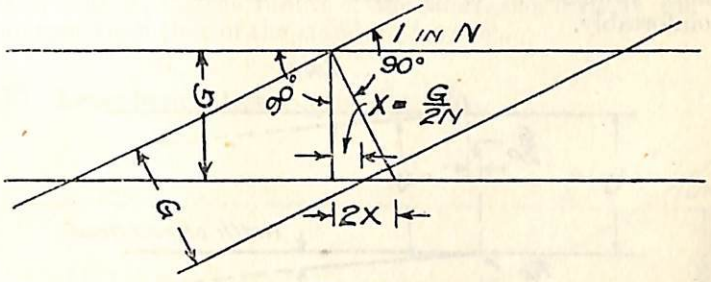


FIG. 94.

The amount of lead 'X' for various angles can be found from Sheet 9 of the Diagrams for Obtaining Leads and Radii (*see* p. 316).

LEAD OF TURNOUTS IN A JUNCTION TO ENSURE TRUE SIXFOOT.

In order that the two tracks of a double line junction shall be concentric, i.e. that the 6′ 5½″ or other space shall be constant throughout, the inner turnout must be set ahead of the outer turnout by the distance 'Y' as shewn in Fig. 86.* This distance is obtained by dividing the sum of the gauge plus the space between the tracks by twice the angle of the turnout crossing, i.e.

$$Y = \frac{S + G}{2N}$$

For example, if the spacing S between the tracks is 6′ 5½″ and the turnout angles are 1 in 12 then

$$Y = \frac{6' 5\tfrac{1}{2}'' + 4' 8\tfrac{1}{2}''}{2 \times 12} = \frac{11' 2''}{24} = 5\tfrac{3}{16}'' \text{ nearly.}$$

The value of Y for various angles can be obtained from Sheet 9 of the Diagrams for Obtaining Leads and Radii (*see* p. 316).

*It is occasionally found necessary to depart from the calculated amount 'Y' in order to suit the run of the switch rodding.

LEAD OF SWITCH RAILS IN SWITCHES TO OBTAIN TRUE GAUGE.

As explained in the chapter on ' Permanent Way Materials—Switches and Crossings ', the British Standard Switch tongues are planed straight for a certain length. From Fig. 95 it will be seen that a pair of switches is equivalent to half of a diamond crossing, of an angle equal to the angle of the switch planing. Therefore the tip of the outer switch rail should lead the tip of the inner switch rail in order that true gauge be maintained at the switches. This matter is important in short switches in order that the stretcher bars may fit comfortably.

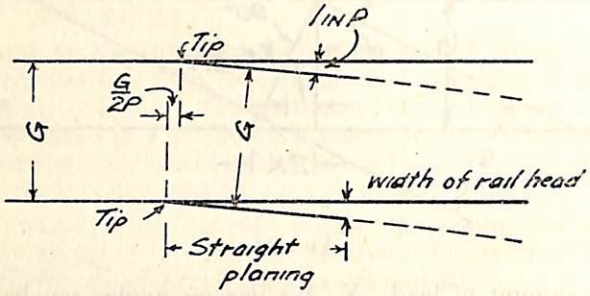


FIG. 95.

The amount the outer switch leads the inner is equal to the gauge divided by twice the angle of the switch planing.

SPECIAL TURNOUTS.

In some cases owing to special circumstances it is necessary to depart from standard leads, and either to lengthen or shorten them. This should only be done, however, in exceptional circumstances, as it is obviously undesirable to depart from standard practice.

The effect of either shortening or lengthening the lead is to sharpen the radius of the turnout curve.

(1) Shortened Lead. (see Fig. 96).

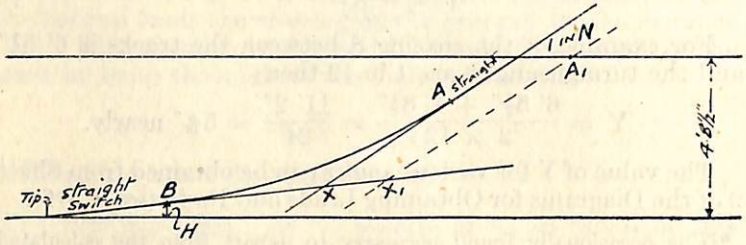


FIG. 96.

The standard position of the crossing is at A_1, the tangent legs BX_1 and X_1A_1 being equal. By shortening the lead the crossing is moved to the left, and this shortens the tangent leg BX_1 to the length BX. As the tangent leg AX must be equal to BX to obtain a truly circular curve, a short length of straight must be inserted between the tangent point A and the crossing.

The angle of intersection between BX and AX is equal to that between BX_1 and A_1X_1 since AX is parallel to A_1X_1, and, therefore, as the tangent legs BX and AX are shorter than BX_1 and A_1X_1, the radius of the shortened turnout will be sharper than that of the standard turnout.

(2) **Lengthened Lead.** (see Fig. 97).

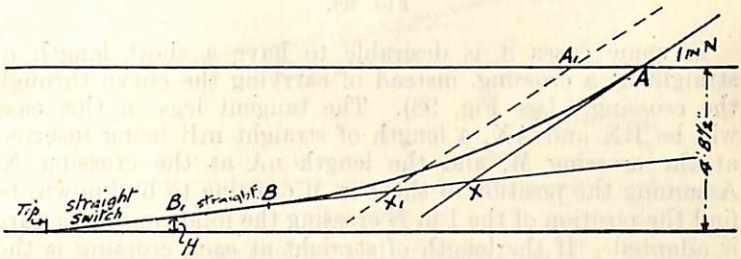


FIG. 97.

The standard position of the crossing is at A_1, the tangent legs B_1X_1 and A_1X_1 being equal. By lengthening the lead the crossing is moved to the right, say to the position A. One tangent leg will then be AX, which, from the figure, is seen to be slightly shorter than A_1X_1. In order to obtain a truly circular curve BX must be equal to AX, and hence the length B_1B of straight must be inserted between the heel of the switch B_1, and the tangent point B.

As the angle of intersection between AX and BX is equal to that between A_1X_1 and B_1X_1, and AX is shorter than A_1X_1, the radius of the lengthened lead, is sharper than that of the standard.

Straight switches are shewn in Figs. 96 and 97, but the results are the same with semi-curved switches.

A shortened or lengthened lead can be set out by the methods previously described. The crossing leg AX must be set up, then in the case of the shortened lead, the length BX is measured, and AX made equal to it. In the case of the

lengthened lead AX must be measured, and BX made equal to it. The turnout curve is set out between points A and B as previously described.

Lengths of straight at crossings.

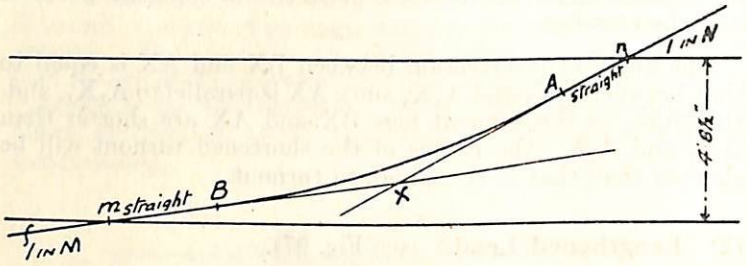


FIG. 98.

In some cases it is desirable to have a short length of straight at a crossing, instead of carrying the curve through the crossing. (*see* Fig. 98). The tangent legs in this case will be BX and AX, a length of straight mB being inserted at the crossing M, and the length nA at the crossing N. Assuming the position of the 1 in M crossing to be known, to find the position of the 1 in N crossing the following procedure is adopted. If the length of straight at each crossing is the same, i.e. mB = nA, the point n must be so positioned that mX and nX are equal in length. Then as mX = nX, and mB = nA, BX must be equal to XA, and therefore as these are the tangent legs, a circular curve can be put in tangential to the crossing legs at points B and A.

If the length of straight mB is to be longer than the length nA, the 1 in N crossing must be so positioned that mX is longer than nX, by the amount that mB exceeds nA.

Similarly if nA is to be longer than mB, the 1 in N crossing must be so positioned that nX is longer than mX, by the amount nA exceeds mB.

In these last two cases it will then be found that BX = XA, and the condition that the tangent legs should be equal is satisfied.

For example if the length of straight mB is to be 10 feet, and the length of straight nA is to be 8 feet, the difference between mB and nA is 2 feet, and the 1 in N crossing must be so positioned that mX is 2 feet longer than nX. The tangent point B will be 10 feet from the fine point of the 1 in M crossing, and the tangent point A will be 8 feet from the fine point of the 1 in N crossing, and BX and AX will be equal in length.

CONVERGING AND DIVERGING SPACING BETWEEN TRACKS.

The method of setting out the positions of crossings between converging or diverging tracks is the same as that used where the tracks are parallel, as shewn in Fig. 99.

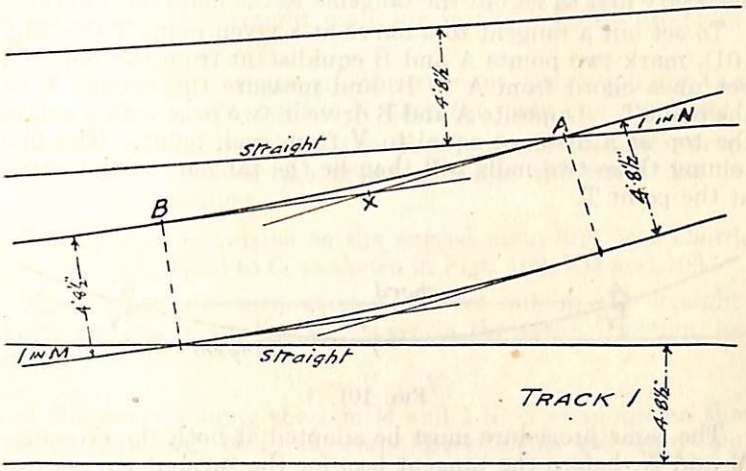


FIG. 99.

The line BX is parallel to, and at a distance of 4′ 8½″ from, the crossing which is at an angle of 1 in M with the track, the tangent point B being square opposite to the fine point of the crossing. The 1 in N crossing must be positioned at A so that BX and AX are equal. The method of inserting the curve between B and A is as previously described.

SETTING OUT POINT AND CROSSING WORK FROM A CURVED MAIN.

When setting out the necessary tangent legs for turnouts or other point and crossing work from curves, it is essential that the angles be set up from the tangent to the main line at the heel of the turnout, or at the fine point of the crossing, as the case may be.

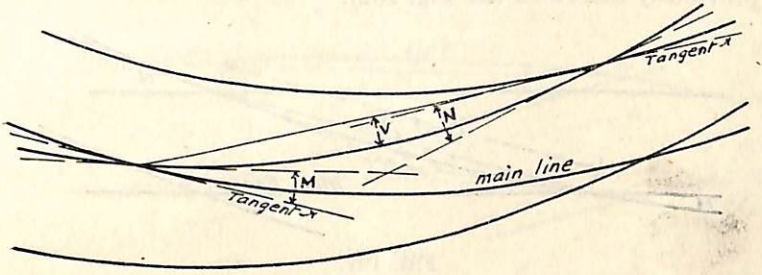


FIG. 100.

Taking the case of two curved tracks crossing each other as in Fig. 100, the angles M and N are the angles between the tangents to the main line, and those to the turnout curves at the fine points of the crossings.

Thus, before these angles can be set out accurately, it is necessary first to set out the tangents to the main line curve.

To set out a tangent to a curve at a given point T (*see* Fig. 101), mark two points A and B equidistant from the point T. Set up a chord from A to B, and measure the versine V at the point T. Opposite A and B drive in two pegs with a nail in the top at a distance equal to V from each point. The line joining these two nails will then be the tangent to the curve at the point T.

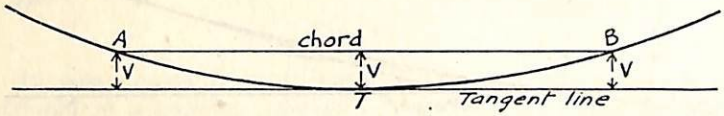


FIG. 101.

The same procedure must be adopted at both the crossings M and N, before the tangent legs for the turnout curves can be obtained, and the work is obviously more complicated than when dealing with a straight main.

As, for all practical purposes, the leads between any given crossings are constant whether the main line is straight or curved, it is preferable first to obtain the required dimensions by setting out on a straight length of track, and then to use the information so obtained for setting out on the curved track.

For example, assume that it is required to set out crossings 1 in M and a 1 in N, crossing the 4′ 8½″ way, the main line being curved.

First obtain the chord length C (fine point to fine point) and the versine V by setting out the positions for the crossings 1 in M and 1 in N on a piece of straight track, by the method previously described (*see* Fig. 102).

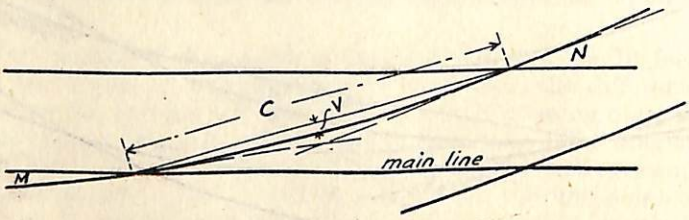


FIG. 102.

Now the chord length C will remain constant whether the main line is straight or curved, but the versine on the turnout curve will be more than V if the main line and the curve joining the 1 in M and the 1 in N crossings (as set out on the straight main) are in the same direction as in Fig. 103, and less than V if the main line and the curve joining the two crossings as set out on the straight main are in the opposite direction as in Figs. 104 and 105.

Let V = the versine on the turnout curve joining the 1 in M and 1 in N when the main line is straight.

Let C = the length of the chord of the turnout curve between the crossings when the main line is straight.

Let V_1 = the versine on the curved main line on a chord equal to C, as shewn in Figs. 103, 104 and 105.

Then, when the turnout curve as set out on the straight main, and the main line curve are in the same direction, as in Fig. 103,

$$V_2 = V + V_1$$

and the curve joining the 1 in M and 1 in N crossings on the curved main will be in the same direction as the main line curve.

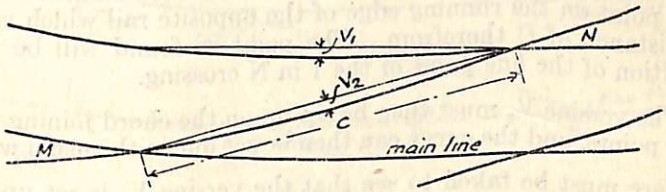


FIG. 103.

When the main line curve is in the opposite direction to the turnout curve as set out on a straight main, $V_2 = V - V_1$, but the following points must be carefully noted :—

(1) If V is greater than V_1, the turnout and main line will be curved in opposite directions, as in Fig. 104.

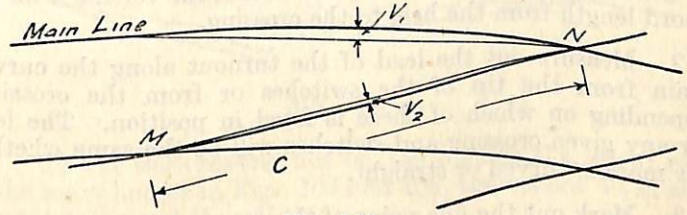


FIG. 104.

(2) If V is equal to V_1, then $V - V_1 = 0$, and the turnout will be straight. As $V_1 = V$ it follows that the main line curve is of the same radius as the curve joining the 1 in M and the 1 in N crossings as set out on a piece of straight track in Fig. 102.

(3) If V is less than V_1, the turnout and main line will be curved in the same directions, and $V_2 = V_1 - V$, as in Fig. 105.

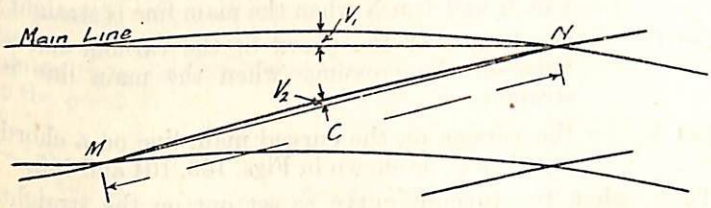


FIG. 105.

Having obtained the value of V_2, the method of setting out is as follows :—

Assuming the position of the 1 in M crossing to be given, hold one end of a tape on the fine point of this crossing, and find the point on the running edge of the opposite rail which is at a distance of C therefrom. The point so found will be the position of the fine point of the 1 in N crossing.

The versine V_2 must then be set up on the chord joining the fine points, and the curve can then be set out in the usual way.

Care must be taken to see that the versine V_2 is set up on the right side of the chord, as mentioned in (1) and (3) above, though any error in this will usually easily be seen by eye.

The method described above can be used for setting out simple turnouts from a curved main and gives the best results. The process is as follows :—

1. Set out the turnout from the heel to the crossing on a length of straight track, in order to obtain the versine V on the chord length from the heel to the crossing.

2. Measure out the lead of the turnout along the curved main from the tip of the switches or from the crossing, depending on which of these is fixed in position. The lead for any given crossing and switches will be the same whether the main is curved or straight.

3. Mark out the fine point of the crossing.

4. Set out on the curved main the position of the heel of the switch from the data given in the tables on p. 45, and measure the chord length C from the heel to the fine point of the crossing.

5. Measure back from the fine point of the crossing towards the switches, the chord length C along the main line, and measure the versine V_1 of the main line curve on this chord.

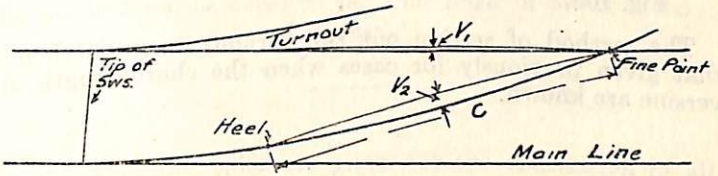


FIG. 106.

6. (*a*) If the crossing lies on the inside (i.e. low) rail of the main line curve as in Fig. 106, the versine V_2 of the turnout will equal $V + V_1$, and the turnout curve will be in the same direction as the main line curve.

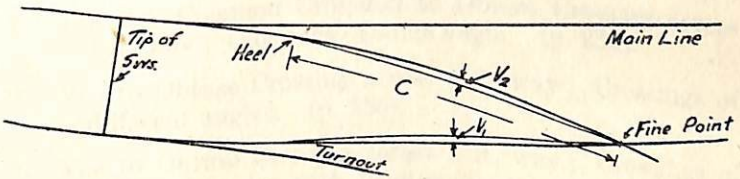


FIG. 107.

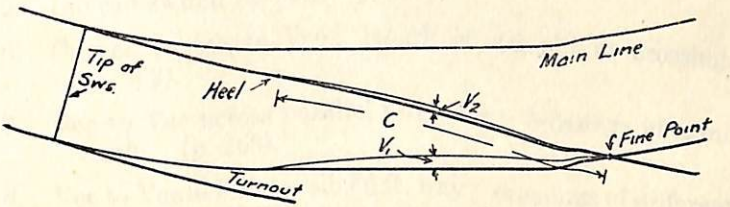


FIG. 108.

(*b*) If the crossing lies on the outside (i.e. high) rail of the main line as in Figs. 107 and 108, the versine V_2 of the turnout will equal $V - V_1$.

In this case—

(1) If V is greater than V_1, the turnout will be curved in the opposite direction to the main, as in Fig. 107.

(2) If V equals V_1, $V - V_1 = 0$ and the turnout will be straight.

(3) If V is less than V_1, the turnout will be curved in the same direction as the main line curve, and $V_2 = V_1 - V$, as in Fig. 108.

The method of setting out the turnout curve is then as that given previously for cases when the chord length and versine are known.

CHAPTER IX

CALCULATION OF LEADS AND RADII.

(By use of Formulæ based on the Unit Angle of Switches and Crossings).

In this Chapter, rules are given for the calculation of all leads and radii normally required, and examples are worked to show how the rules should be used. In Chapter X, the results obtained by these rules are used to build up the complete dimensions required for such work as a double line junction, a scissors crossover, etc.

The various types of lead for which calculations are given in this Chapter are :—

1. Vee (i.e. Common Crossing) to Obtuse Crossing across 4 ft. way ; Crossings of same angle. (p. 254).
2. Vee to Obtuse Crossing across 4 ft. way ; Crossings of different angles. (p. 256).
3. Vee to Obtuse Crossing across 4 ft. way ; Crossings of different angles with lengths of straight at crossings. (p. 257).
4. Straight switch to Vee. (p. 259).
5. Curved switch to Vee. (p. 260).
6. Curved switch to Vee ; length of straight at crossing. (p. 262).
7. Vee to Vee across parallel 6 ft. way ; crossings of same angle. (p. 263).
8. Vee to Vee across parallel 6 ft. way ; crossings of different angles. (p. 265).
9. Vee to Vee across converging 6 ft. way ; crossings of different angles. (p. 266).
10. Vee to Vee across diverging 6 ft. way ; crossings of different angles. (p. 268).

In most cases a worked example is given. The standard symbols given below are used throughout the calculations.

C	=	Chord.
C_s	=	Subchord.
G	=	Gauge of track.
H	=	Clearance at Switch Heel.
L	=	Lead, crossing to crossing, or heel of switch to crossing, as the case may be.
l	=	Length of switch from toe to heel.
R	=	Radius.
S	=	Spacing between tracks.
V	=	Versine.
V_s	=	Subversine.
N and M	=	Unit angles of crossings, based on the centre line method of measurement.
m	=	Average of the angles of two crossings of angles M and N, in units.
m_s	=	Sum of the angles of two crossings of angles M and N, in units.
m_d	=	Difference between the angles of two crossings of angles M and N, in units.

Before proceeding with the calculation of leads, it is necessary to note the following rules with regard to the average, sum and difference of unit angles, and to the measurement of unit angles.

Let M and N equal the unit angles of two crossings.

,, m equal the average of two angles M and N.

,, m_s equal the sum ,, ,, ,,

,, m_d equal the difference ,, ,, ,,

then $m = \frac{2MN}{M+N}$ **(Rule 1)**

$m_s = \frac{MN}{M+N}$ **(Rule 2)**

$m_d = \frac{MN}{M-N}$ **(Rule 3)**

These rules are approximate, but the error is negligible with angles of the magnitude in use in permanent way work.

Examples.—

(*a*) What is the average of two crossings of unit angles 8 and 6 ?

$$m = \frac{2 \times 8 \times 6}{8 + 6} = \frac{96}{14} = 6{\cdot}86 = 1 \text{ in } 6{\cdot}86$$

(*b*) What is the sum of two crossings of unit angles 8 and 6 ?

$$m_s = \frac{8 \times 6}{8 + 6} = \frac{48}{14} = 3{\cdot}43 = 1 \text{ in } 3{\cdot}43$$

(*c*) What is the difference between two crossings of unit angles 8 and 6 ?

$$m_d = \frac{8 \times 6}{8 - 6} = \frac{48}{2} = 24 = 1 \text{ in } 24$$

It should also be noted that if an angle N is bisected it will be divided into two angles each of 2N, as shewn in Fig. 109.

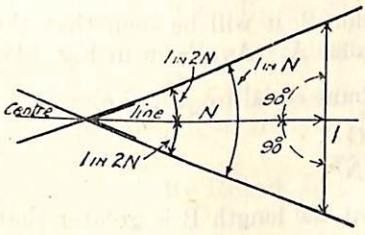


Fig. 109.

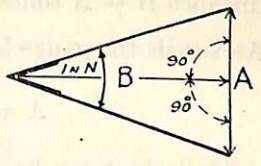


Fig. 110.

The principle of Centre Line Measure has already been explained in Chapter III. In Fig. 110 shewing an angle 1 in N, given the dimensions A and B, then :—

$$N = \frac{B}{A} \qquad \textbf{(Expression 1)}$$

$$\text{Whence } B = NA \qquad \textbf{(Expression 2)}$$

Expressed in words these formulæ mean that, (1) the unit angle of the crossing is the length B divided by the length A ; and, (2) that the length B may be found by multiplying together the unit angle of the crossing and the length A.

The expression B = NA is the basis of all the formulæ now to be considered.

LEAD ACROSS 4′ 8½″ WAY. ORDINARY TO OBTUSE CROSSING.

Case 1. Crossings of equal angle.

The track joining the two crossings will be straight as shewn in Fig. 111.

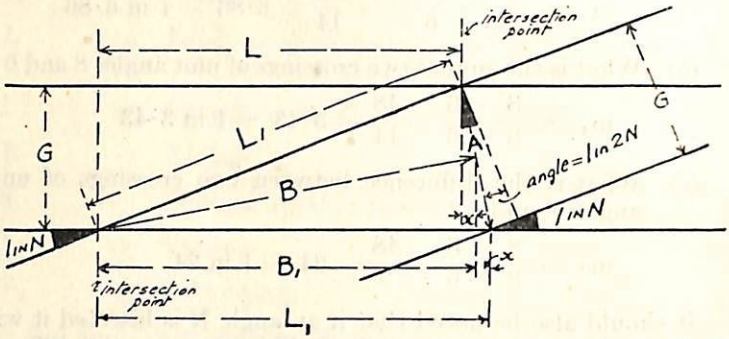


FIG. 111.

From Fig. 111, and Expression 2, it will be seen that the distance B = N times the distance A. As shewn in Fig. 147, A exceeds the gauge by an amount equal to $\frac{G}{8N^2}$, i.e.

$$A = G + \frac{G}{8N^2}$$

Similarly it can be shewn that the length B is greater than B_1 by an amount equal to $\frac{x}{2}$. Now x is half the square distance between the obtuse crossing, i.e. $x = \frac{1}{2}X$ in Fig. 94.

On p. 240 it is stated that $X = \frac{G}{2N}$ whence $\frac{x}{2} = \frac{G}{8N}$

$$\therefore B = B_1 + \frac{G}{8N}$$

Substituting these values for B and A in the Expression B = NA,

$$\text{We have } B_1 + \frac{G}{8N} = N\left(G + \frac{G}{8N^2}\right)$$

$$\text{i.e.} \qquad B_1 + \frac{G}{8N} = NG + \frac{G}{8N}$$

$$\text{whence} \quad B_1 = NG$$

From Fig. 111, it will be seen that B_1 is greater than the lead L by the amount x, this amount being equal to the gauge divided by four times the angle of the diamonds.

i.e. $x = \frac{G}{4N}$.

$$\therefore L = B_1 - \frac{G}{4N} = NG - \frac{G}{4N} \qquad \textbf{(Rule 4)}$$

This Rule gives the lead to intersection points.

From Fig. 111 it will be seen that the lead of one obtuse crossing over the other, measured along the main, is 2x. Therefore the distance from intersection point of the common crossing to the knee of the obtuse crossing, marked L_1, in Fig. 111, is L + 2x.

$$\text{Now } L = NG - \frac{G}{4N} \text{ and } x = \frac{G}{4N}$$

$$\therefore L_1 = NG - \frac{G}{4N} + 2 \times \frac{G}{4N}$$

$$\text{i.e. } L_1 = NG + \frac{G}{4N} \qquad \textbf{(Rule 5)}$$

Example.—What is the lead L when the gauge = 4′ 8½″ and the crossing angle in units is 1 in 8 ?

$$\text{By Rule 4, } L = NG - \frac{G}{4N}$$

$$= 8 \times 4' \, 8\tfrac{1}{2}'' - \frac{4' \, 8\frac{1}{2}''}{32}$$

$$= 37' \, 8'' - 1\tfrac{3}{4}''$$

$$= 37' \, 6\tfrac{1}{4}''$$

The above lead is given to intersection points. To obtain the lead to the actual nose, the distance from intersection point to actual nose for a 1 in 8 crossing must be added thereto.

This distance is found by multiplying the angle of crossing by the width of nose—(*see* Fig. 112). For the standard width of nose of ¾″ the distance in this case is $8 \times \frac{3}{4} = 6''$.

$$L + Nw = 37' \, 6\tfrac{1}{4}'' + 8 \times \tfrac{3}{4}''$$

$$= 37' \, 6\tfrac{1}{4}'' + 6''$$

i.e. Lead to blunt nose = 38′ 0¼″

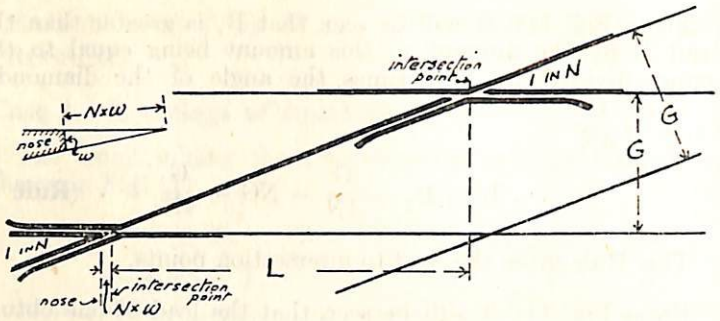


FIG. 112.

Case 2. Crossings of unequal angle.

The track joining the two crossings will be curved as shewn in Fig. 113.

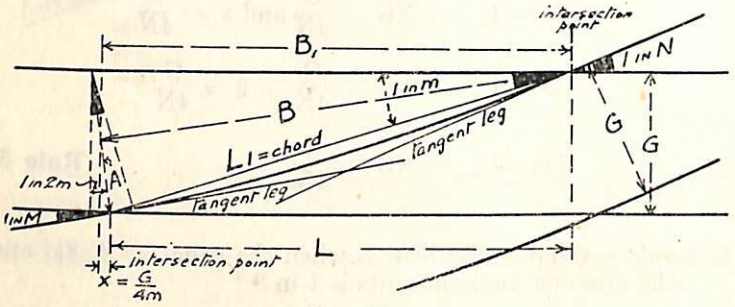


FIG. 113.

As stated in the section dealing with the properties of the Circle, *see* page 196, to ensure a circular curve between any two tangent points, both tangent legs must be of equal length. The intersection points of the crossings will be the tangent points in this case. A line joining the two crossings M and N will be the chord, and the angle between the chord and either running edge will be equal to half the sum of the two angles M and N, i.e. 1 in m, the average angle of the two crossings.

The lead will then be equivalent to that of a track joining two crossings of angle 1 in m across the 4′ 8½″ way and the rule for obtaining the lead L will be of the same form as Rule 4, ' m ' being substituted for ' N ' thus :—

$$L = m\,G - \frac{G}{4m} \qquad \textbf{(Rule 6)}$$

The rule for obtaining the chord length will be of the same form as Rule 5, with ' m ' substituted for ' N '.

$$\text{i.e. } L_1 = mG + \frac{G}{4m} \qquad \textbf{(Rule 7)}$$

Example.—What is the lead L when the gauge of track is 4′ 8½″ and the angles of crossings are 1 in 8 and 1 in 6 ?

$$\text{By Rule 6, } L = mG - \frac{G}{4m}$$

Now m = average angle of the crossings M and N, which in this example are 1 in 8 and 1 in 6, and G = 4·71′.

$$\text{By Rule 1, } m = \frac{2\,MN}{M+N} = \frac{2 \times 8 \times 6}{8+6} = \frac{96}{14} = 6{\cdot}86$$

Insert this value for m in the expression $L = mG - \frac{G}{4m}$

thus:—
$$L = 6{\cdot}86 \times 4{\cdot}71 - \frac{4{\cdot}71}{4 \times 6{\cdot}86}$$
$$= 32{\cdot}31 - {\cdot}17$$
$$= 32{\cdot}14$$
$$= 32′\ 1\tfrac{5}{8}″$$

(It will be noticed that the values of m and G are expressed in decimals of a foot. The rules for conversion are given on page 187).

It must be observed that the lead L is to intersection points. To obtain the lead to actual nose proceed as explained in the previous example, noting that the amount to be added must be the distance from intersection to actual nose of the Ordinary Crossing, the knee of the diamond crossing being also the intersection point.

Case 3. Short length of straight at both crossings.

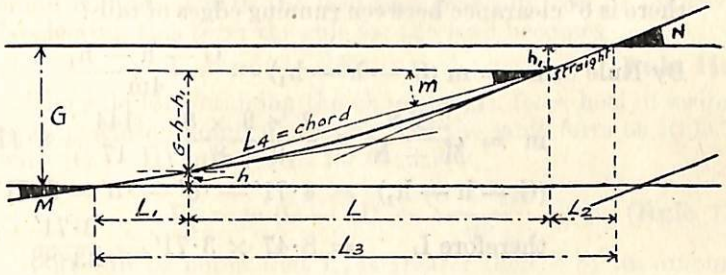


FIG. 114

In certain cases it is desirable to have a short length of straight through the crossings. The clearances marked h and h_1 indicate the distance between running edges of rails at the ends of the straight portions of the crossings, i.e. at the tangent points of the lead curve.

The dotted lines in Fig. 114 are drawn through the ends of the straights at the crossings and parallel to the rails of the

main, i.e. at distances h and h_1 respectively from the main rails. The angles between these dotted lines and the straights at the crossings are then 1 in M and 1 in N respectively, and it will be seen that the problem is similar to that of ascertaining the lead between crossings of 1 in M and 1 in N across a gauge equal to $(G - h - h_1)$, with a curve from crossing to crossing.

The rule for obtaining the lead between the ends of the crossing straights is therefore of the same form as Rule 6, with $(G - h - h_1)$ substituted for G.

i.e. in Fig. 114, $L = m(G - h - h_1) - \frac{(G - h - h_1)}{4m}$ **(Rule 8)**

where m is the average of the two crossing angles.

If both crossings are of the same angle N the rule becomes

$$L = N(G - h - h_1) - \frac{(G - h - h_1)}{4N} \qquad \textbf{(Rule 9)}$$

From Fig. 114, $L_3 = L + L_1 + L_2$

where $L_1 = Mh$ and $L_2 = Nh_1$

The rule for obtaining the chord length will be of the same form as Rule 7, with $(G - h - h_1)$ substituted for G, i.e.

$$L_4 = m(G - h - h_1) + \frac{(G - h - h_1)}{4m} \qquad \textbf{(Rule 10)}$$

Example.—What is the lead for a track crossing the 4′ 8½″ way with 1 in 9 crossing and 1 in 8 diamonds, both crossing and diamonds being straight to a point where there is 6″ clearance between running edges of rail ?

By Rule 8, $L = m(G - h - h_1) - \frac{G - h - h_1}{4m}$

$$m = \frac{2MN}{M + N} = \frac{2 \times 9 \times 8}{9 + 8} = \frac{144}{17} = 8{\cdot}47$$

$$(G - h - h_1) = 4{\cdot}71' - {\cdot}5' - {\cdot}5' = 3{\cdot}71'$$

$$\text{therefore } L = 8{\cdot}47 \times 3{\cdot}71' - \frac{3{\cdot}71'}{33{\cdot}88}$$

$$= 31{\cdot}42' - {\cdot}11' = 31{\cdot}31'$$

$$= 31'\ 3\tfrac{3}{4}''$$

$$L_1 = M \times h = 9 \times 6'' = 4'\ 6''$$

$$L_2 = N \times h_1 = 9 \times 6'' = 4'\ 0''$$

$$\text{therefore } L_3 = 31'\ 3\tfrac{3}{4}'' + 4'\ 6'' + 4'\ 0''$$

$$= 39'\ 9\tfrac{3}{4}'' \text{ (to intersection points).}$$

LEAD OF TURNOUT WITH STRAIGHT TYPE SWITCHES.

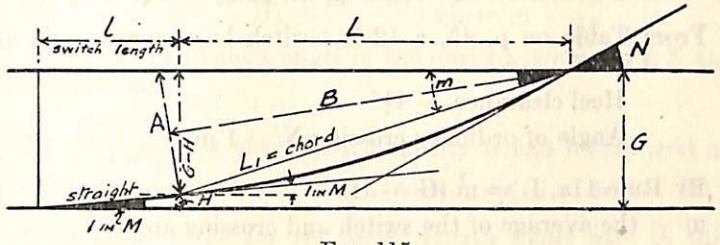


FIG. 115.

Let the angle of the switch be M, (which with straight type switches is the length of switch divided by the heel offset, (*see* p. 44), and let the angle of the crossing be N.

By reference to Fig. 115, it will be seen that the problem is that of obtaining the lead between two Crossings 1 in M and 1 in N across a gauge equal to G — H.

The rule for obtaining the lead is therefore of the same form as Rule 6, with (G — H) substituted for G ; i.e.

$$L = m\,(G - H) - \frac{(G - H)}{4m} \qquad \textbf{(Rule 11)}$$

In the above rule 'm' is the average of the two angles M and N.

In the case of turnouts the last term, $\frac{G - H}{4m}$, is usually small compared with the lead and generally can be omitted. Neglecting this term the rule for the lead becomes

$$L = m\,(G - H). \qquad \textbf{(Rule 11a)}$$

The rule for obtaining the chord length from heel of switch to intersection point of crossing is of the same form as Rule 7, with (G — H) substituted for G ; i.e.

$$L_1 = m\,(G - H) + \frac{(G - H)}{4m} \qquad \textbf{(Rule 12)}$$

It will be noted that L_1 is greater than L by an amount equal to $\frac{(G - H)}{2m}$

∴ if Rule 11a is used to obtain the lead, L_1 will be

$$L + \frac{(G - H)}{2m}$$

i.e., $L_1 = m\,(G - H) + \frac{(G - H)}{2m}$ **(Rule 12a)**

Example.—What is the lead of turnout from tip of switch to nose of crossing for a 12 ft. switch with $4\frac{1}{2}''$ clearance at the heel, and a 1 in 7 crossing, the gauge being 4′ $8\frac{1}{2}''$?

From Table on p. 45, a 12 ft. switch has a unit angle of 1 in 32.

Heel clearance = $4\frac{1}{2}''$

Angle of ordinary crossing N = 1 in 7.

By Rule 11a, L = m (G — H).

m = the average of the switch and crossing angles,

$$\text{i.e., } m = \frac{2\,MN}{M + N} = \frac{2 \times 32 \times 7}{32 + 7} = \frac{448}{39} = 11{\cdot}49$$

$$G - H = 4'\ 8\tfrac{1}{2}'' - 4\tfrac{1}{2}'' = 4'\ 4'' = 4{\cdot}33'$$

Inserting these values in Rule 11a thus :—

$$L = 11{\cdot}49 \times 4{\cdot}33'$$
$$= 49{\cdot}75'$$
$$= 49'\ 9''$$

Lead L is from heel of switch to intersection of crossing, therefore to obtain the full lead, the switch length plus the distance from intersection to nose, must be added thereto, i.e.,

L	=	49′	9″
Switch length ..	=	12′	0″
Intersection to nose = $7 \times \frac{3}{4}''$	=		$5\frac{1}{4}''$
Full Lead ..	=	62′	$2\frac{1}{4}''$

LEAD OF TURNOUT WITH CURVED TYPE SWITCHES.

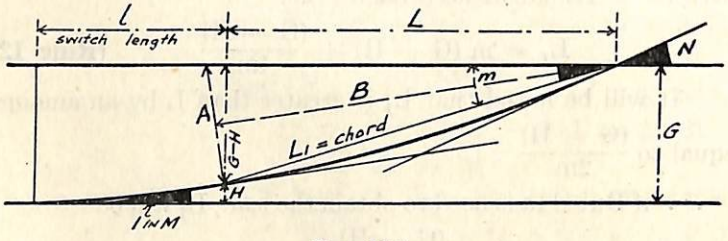


FIG 116.

This problem is similar to the previous one with the exception that the equivalent angle of switch has to be used (*see*

details of curved switches, page 45). The formula is the same as that for the lead of turnout with straight switches, (Rule 11) viz. : $L = m(G - H) - \frac{G - H}{4m}$, where $m = \frac{2MN}{M + N}$

M being the equivalent angle of the curved switch, and N the crossing angle.

As $\frac{G - H}{4m}$ is a very small quantity it can be omitted as previously explained, and Rule 11a used, viz. $L = m(G - H)$.

Rule 12 and 12a for the chord length apply also to this problem.

Example.—What is the lead of turnout from tip of switch to actual nose of crossing for a 'C' type REA switch with a 1 in 8 crossing, the gauge being 4′ 8½″ ?

From Table on p. 45, a 'C' type REA switch has an equivalent angle of 1 in 22·68 = M

The gauge G = 4′ 8½″ = 4·71′

The heel clearance H from Table on p. 45, = 10$\frac{5}{16}$″ = ·86″

Angle of ordinary crossing N = 1 in 8.

By Rule 11a—

$L = m(G - H)$

m = the average of the switch and crossing angles

$$= \frac{2MN}{M + N} = \frac{2 \times 22{\cdot}68 \times 8}{22{\cdot}68 + 8} = \frac{362{\cdot}88}{30{\cdot}68} = 11{\cdot}83$$

$G - H = 4{\cdot}71' - {\cdot}86' = 3{\cdot}85'$

Inserting these values in Rule 11a,

$$L = 11{\cdot}83 \times 3{\cdot}85$$
$$= 45{\cdot}55'$$
$$= 45' \; 6\tfrac{5}{8}''$$

The Lead L is from heel of switch to intersection point of crossing, therefore the switch length plus the distance, intersection to nose of crossing, must be added thereto.

L	=	45′ 6⅝″
Switch length for 'C' switch	=	27′ 5″
Intersection to nose = 8 × ¾″ ..		6″
Full lead ..	=	73′ 5⅝″

TURNOUT LEAD WITH SHORT PIECE OF STRAIGHT AT THE CROSSING.

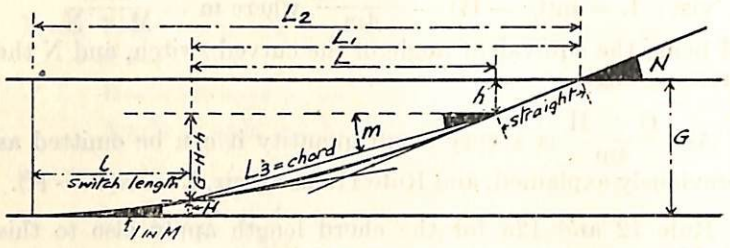


FIG. 117.

In some cases it is desired to have a short piece of straight through the crossing of a turnout. The turnout curve will then be from the switch heel to the end of the straight through the crossing, where the clearance to the main is 'h', *see* Fig. 117. The problem is similar to that of finding the lead across a gauge equal to (G — H — h) between two crossings 1 in M and 1 in N.

Rule 11 with (G — H — h) substituted for (G — H) can therefore be used, this giving the lead marked L in Fig. 117 ; i.e.

$$L = m(G - H - h) - \frac{(G - H - h)}{4m}$$

To obtain the lead L_1 from the switch heel to the intersection point of the crossing, the distance from the clearance h to the intersection point, which equals N × h, must be added to L,

$$\therefore L_1 = m(G - H - h) - \frac{(G - H - h)}{4m} + Nh \quad \textbf{(Rule 13)}$$

As mentioned in the previous case $\frac{(G - H - h)}{4m}$ is generally small compared with the lead and can be omitted unless great accuracy is required. If this is done

$$L_1 = m(G - H - h) + Nh \quad \textbf{(Rule 13a)}$$

The rules for obtaining the chord length L_3 are of the same form as Rules 12 and 12a with (G — H — h) substituted for (G — H), i.e.

$$L_3 = m(G - H - h) + \frac{(G - H - h)}{4m} \quad \textbf{(Rule 14)}$$

or if Rule 13a is used to obtain L

$$L_3 = m(G - H - h) + \frac{(G - H - h)}{2m} \quad \textbf{(Rule 14a)}$$

LEAD ACROSS 6′ 5½″ OR OTHER SPACING BETWEEN TRACKS.

Case 1. Crossings of equal angle.

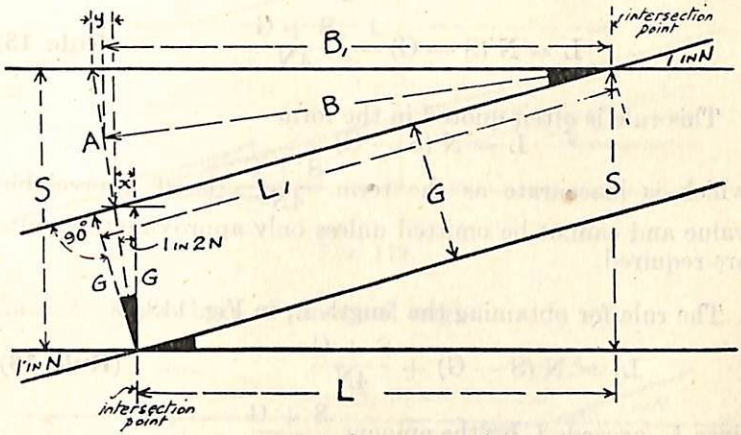


FIG. 118.

The Track will be straight between the crossings as shewn in Fig. 118.

By similar reasoning to that on p. 254,

$$B = B_1 + \frac{y}{4} \text{ and } y = \frac{S - G}{2N}$$

$$\therefore B = B_1 + \frac{(S - G)}{8N}$$

Also the length A exceeds the distance (S — G) by an amount equal to $\frac{(S - G)}{8N^2}$ i.e. $A = (S - G) + \frac{(S - G)}{8N^2}$, (*see* p. 299).

By Expression 2, B = NA, $\therefore$ substituting the above values for B and A in this expression

$$B_1 + \frac{(S - G)}{8N} = N\left((S - G) + \frac{(S - G)}{8N^2} \right)$$

$$\text{i.e. } B_1 + \frac{(S - G)}{8N} = N(S - G) + \frac{(S - G)}{8N}$$

$$\therefore B_1 = N(S - G)$$

Now B_1 is greater than the lead L by the amount $x + y/2$, *see* Fig. 118.

$$\text{Also } x = \frac{G}{2N} \text{ and } \frac{y}{2} = \frac{S - G}{4N}$$

$$\therefore x + \frac{y}{2} = \frac{G}{2N} + \frac{S - G}{4N} = \frac{S + G}{4N}$$

As explained on p. 263, $L = B_1 - (x + \frac{y}{2})$, whence, substituting the values for B_1 and $(x + \frac{y}{2})$, we have

$$L = N(S - G) - \frac{S + G}{4N} \qquad \textbf{(Rule 15)}$$

This rule is often quoted in the form

$$L = N(S - G)$$

which is inaccurate as the term $\frac{S + G}{4N}$ is of appreciable value and cannot be omitted unless only approximate results are required.

The rule for obtaining the length L_1 in Fig. 118, is

$$L_1 = N(S - G) + \frac{S + G}{4N} \qquad \textbf{(Rule 16)}$$

since L_1 exceeds L by the amount $\frac{S + G}{2N}$

Example.—What is the lead L when the spacing between running edges of track is 6′ 5½″, the gauge is 4′ 8½″ and angle of the crossings is 1 in 8 ?

By Rule 15, $L = N(S - G) - \frac{S + G}{4N}$

∴ substituting the given values of N, S and G

$$L = 8(6' 5\tfrac{1}{2}'' - 4' 8\tfrac{1}{2}'') - \frac{6' 5\tfrac{1}{2}'' + 4' 8\tfrac{1}{2}''}{4 \times 8}$$

$$= 8 \times 1' 9'' - \frac{11' 2''}{32}$$

$$= 14' 0'' - 4\tfrac{3}{16}''$$

$$= 13' 7\tfrac{13}{16}''$$

This lead is given to intersection points ; to obtain the lead to actual noses, twice the distance from intersection point to actual nose for a 1 in 8 crossing must be deducted therefrom. With ¾″ standard width of nose this will be twice the unit angle of crossing multiplied by ¾″ (*see* Fig. 119).

∴ Lead from blunt nose to blunt nose $= 13' 7\tfrac{13}{16}'' - 2 \times 8 \times \tfrac{3}{4}''$

$$= 13' 7\tfrac{13}{16}'' - 12''$$

$$= 12' 7\tfrac{13}{16}''$$

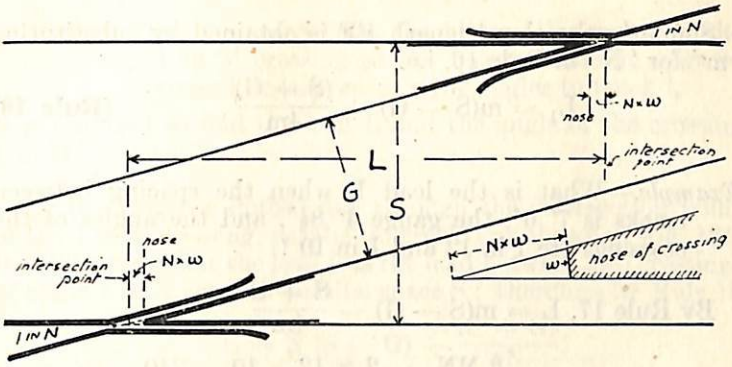


FIG. 119.

Case 2. Crossings of unequal angle.

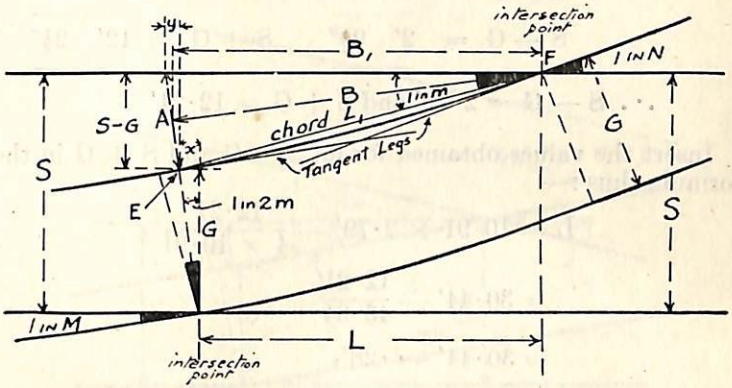


FIG. 120.

The track will be curved between the crossings and as shewn in Fig. 120, the curve is tangential to a line 4′ 8½″ from the crossing rail of the 1 in M crossing, at a point E, square opposite to the intersection point of this crossing, and to the 1 in N crossing at the intersection point F. As explained on p. 196, the tangent legs must be of equal length, and the line joining E and F will be the chord, the angle it makes with the main being 1 in m, which is the average of the two angles M and N.

The lead will then be the same as that of a track joining two crossings 1 in m across the space ' S ', and the rule for obtaining the lead L will be of the same form as Rule 15, with ' m ' substituted for ' N ', i.e.

$$L = m(S - G) - \frac{(S + G)}{4m} \qquad \textbf{(Rule 17)}$$

Similarly the chord length EF is obtained by substituting 'm' for 'N' in Rule 16, i.e.

$$L_1 = m(S - G) + \frac{(S + G)}{4m} \qquad \textbf{(Rule 18)}$$

Example.—What is the lead L when the spacing between tracks is 7′ 6″, the gauge 4′ 8½″, and the angles of the crossings are 1 in 12 and 1 in 10 ?

By Rule 17, $L = m(S - G) - \frac{S + G}{4m}$

By Rule 1, $m = \frac{2\,MN}{M + N} = \frac{2 \times 12 \times 10}{12 + 10} = \frac{240}{22} = 10{\cdot}91$

also S	=	7′ 6″	S	=	7′ 6″
G	=	4′ 8½″	G	=	4′ 8½″
S − G	=	2′ 9½″	S + G	=	12′ 2½″

$\therefore$ S − G = 2·79′ and S + G = 12·21′

Insert the values obtained for m, S − G and S + G in the formula thus :—

$$L = 10{\cdot}91 \times 2{\cdot}79' - \frac{12{\cdot}21'}{4 \times 10{\cdot}91}$$

$$= 30{\cdot}44' - \frac{12{\cdot}21'}{43{\cdot}64}$$

$$= 30{\cdot}44' - {\cdot}28'$$

$$= 30{\cdot}16'$$

$$= 30' \, 1\tfrac{15}{16}''$$

It must be noted that the lead L = 30′ 1$\frac{15}{16}$″ is to intersection points. To obtain the lead to actual nose of crossing proceed as explained in the previous examples.

LEAD BETWEEN CROSSINGS WHEN THE SPACING IS NOT PARALLEL.

Case 1. Space converging.

When the following information is known :—

1. The angle of the crossing 1 in N.
2. The angle of convergence of the tracks 1 in D.
3. The position of the 1 in M crossing.

4. The distance S from the intersection point of the 1 in M crossing to the nearest running edge of track 1, measured at right angles to track 1,

it is required to find the lead L and the angle of the crossing 1 in M.

By drawing the dotted line through the intersection point of the 1 in M crossing, parallel to track 1 as shewn in Fig. 121, it will be seen that the lead L is the lead between two crossings of angle 1 in N across a parallel space S ; therefore by Rule 15

$$L = N\,(S - G) - \frac{(S + G)}{4N}$$

Also from the figure it will be seen that the angle M equals the sum of the angles N and D ; i.e. $M = \frac{DN}{D + N}$ (by Rule 2)

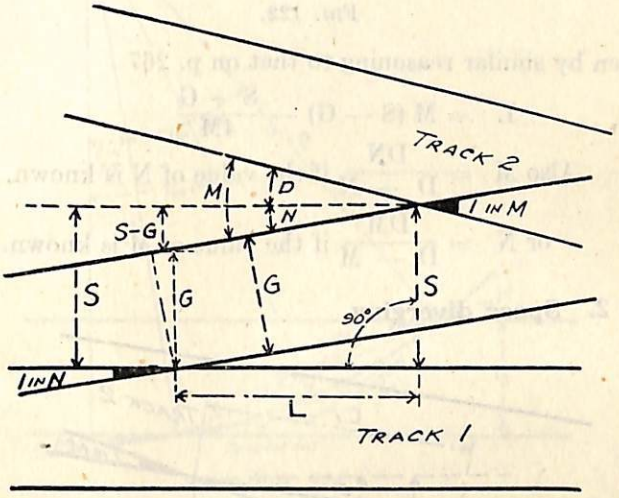


FIG. 121.

If the angle of the crossing M is fixed in value, the angle of the crossing N to give a straight alignment across the converging space will be the difference between the angle of the crossing M and the angle D ; i.e. $N = \frac{DM}{D - M}$ (by Rule 3).

If the position of the crossing N is given the distance S must be measured from the intersection point of this crossing to the running edge of track 2 at right angles to track 2 as shewn in Fig. 122.

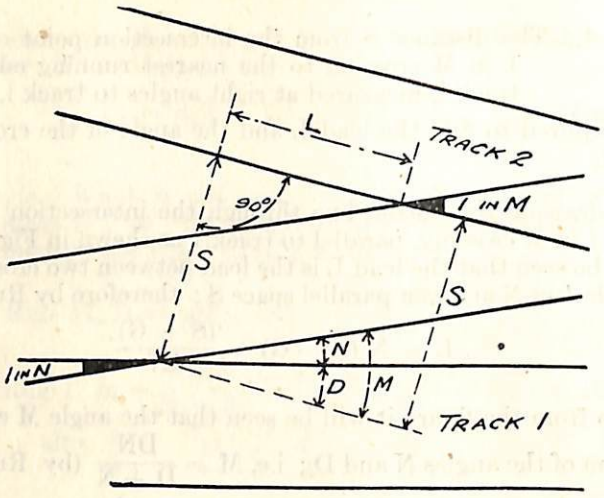


FIG. 122.

Then by similar reasoning to that on p. 267

$$L = M(S - G) - \frac{S + G}{4M}$$

Also $M = \frac{DN}{D + N}$ if the value of N is known.

or $N = \frac{DM}{D - M}$ if the value of M is known.

Case 2. Space diverging.

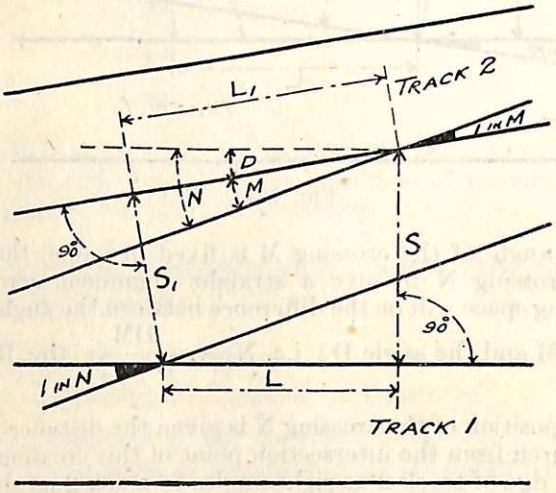


FIG. 123.

By the same reasoning as in Case 1, in Fig. 123

$$L = N(S - G) - \frac{S + G}{4N}$$

$$\text{and } L_1 = M(S_1 - G) - \frac{S_1 + G}{4M}$$

$$\text{also } M = \frac{DN}{D - N} \text{ if the value of N is known,}$$

$$\text{or } N = \frac{DM}{D + M} \text{ if the value of M is known.}$$

RADIUS OF TRACK CROSSING 4′ 8½″ WAY.

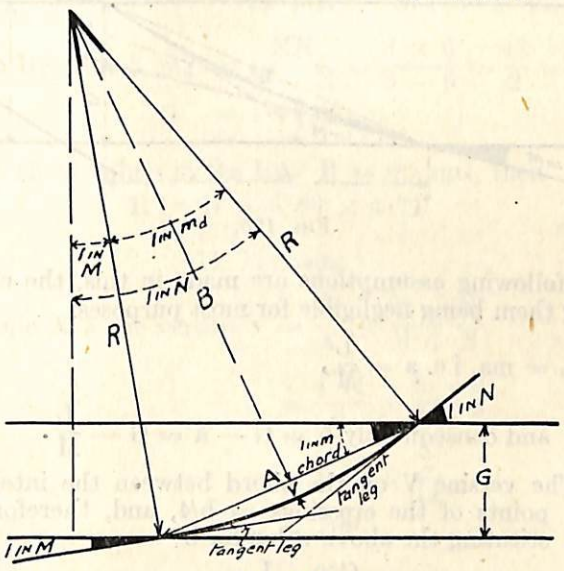


FIG. 124.

In obtaining the radius the distance 'B' in Fig. 124 is assumed equal to the radius 'R', i.e. the versine 'V' is neglected as being small in comparison with the radius. Then, by Expression 2, and reference to Fig. 124,

$$B = R = m_d A$$

where A is the chord length joining the intersection points of the crossings, and m_d is the difference between the angles M and N.

By Rule 7, the chord length $A = mG + \frac{G}{4m}$

where m is the sum of the angles M and N.

. . . substituting this value in the above equation

$$R = m_d\left(mG + \frac{G}{4m}\right) = m_d mG + \frac{m_d G}{4m}$$

The term $\frac{m_d G}{4m}$ is usually small compared with the radius, and can be omitted. The equation then becomes

$$R = m_d mG \qquad \textbf{(Rule 19)}$$

VERSINE ON TRACK CROSSING 4′ 8½″ WAY.

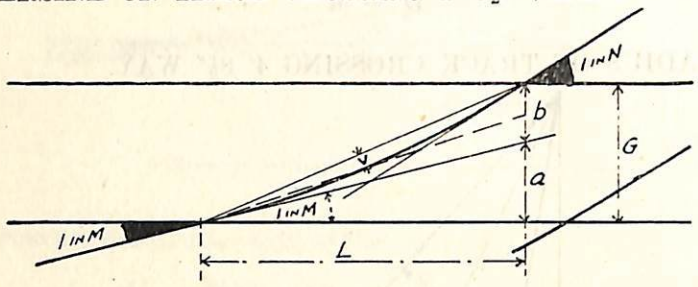


Fig. 125.

The following assumptions are made in this, the errors in making them being negligible for most purposes.

1. $L = ma$, i.e. $a = \frac{L}{M}$,

   and consequently $b = G - a = G - \frac{L}{M}$.

2. The versine V on the chord between the intersection points of the crossings = b/4, and, therefore, substituting the above value for b

$$V = \frac{G}{4} - \frac{L}{4M}$$

By Rule 6, $L = mG - \frac{G}{4m}$. The last term of this is small compared with the lead L and can be omitted. Substituting the value of $L = mG$ in the above expression for V we have

$$V = \frac{G}{4} - \frac{mG}{4M} \qquad \textbf{(Rule 20)}$$

Substituting the value of m in the above and simplifying we obtain

$$V = \frac{G}{4} \times \frac{M - N}{M + N} \qquad \textbf{(Rule 20a)}$$

Either Rule 20 or Rule 20a may be used, whichever is the more convenient, but in using Rule 20 it must be remembered that M is the flatter of the two crossings M and N.

Example.—What is the radius and versine of the curve between ordinary and obtuse crossings when the Gauge = 4′ 8½″ and the crossings are 1 in 8 and 1 in 6 ?

By Rule 19, the radius R = m_d mG.

Values for m and m_d must be first obtained.

$$\text{By Rule 1, } m = \frac{2MN}{M+N} = \frac{2\times8\times6}{8+6} = \frac{96}{14} = 6{\cdot}86$$

$$\text{By Rule 3, } m_d = \frac{MN}{M-N} = \frac{8\times6}{8-6} = \frac{48}{2} = 24$$

$$G = 4{\cdot}71'$$

Insert these values in the Rule R = m_d mG, then

$$R = 24 \times 6{\cdot}86 \times 4{\cdot}71'$$
$$= 775'$$
$$= 11{\cdot}74 \text{ chains}$$

$$\text{By Rule 20 a the versine } V = \frac{G}{4} \times \frac{M-N}{M+N}$$

$$= \frac{4{\cdot}71}{4} \times \frac{8-6}{8+6}$$

$$= 1{\cdot}18 \times \frac{2}{14}$$

$$= {\cdot}17'$$

$$= 2''$$

RADIUS AND VERSINE OF TURNOUT CURVE.

By similar reasoning to that on p. 269 and reference to Fig. 126 it will be seen that the rule for obtaining the radius of the Turnout curve is of the same form as Rule 19 substituting therein (G — H) for ‘ G ’ thus

$$R = m_d\, m(G - H) \qquad \textbf{(Rule 21)}$$

Example (*a*).—What is the radius of the turnout curve for a 12 ft. straight switch with a 1 in 7 crossing, gauge 4′ 8½″ ?

Angle of 12 ft. straight type switch from Table on p. 45.

$$= \frac{12'\ 0''}{4\frac{1}{2}''} = 1 \text{ in } 32$$

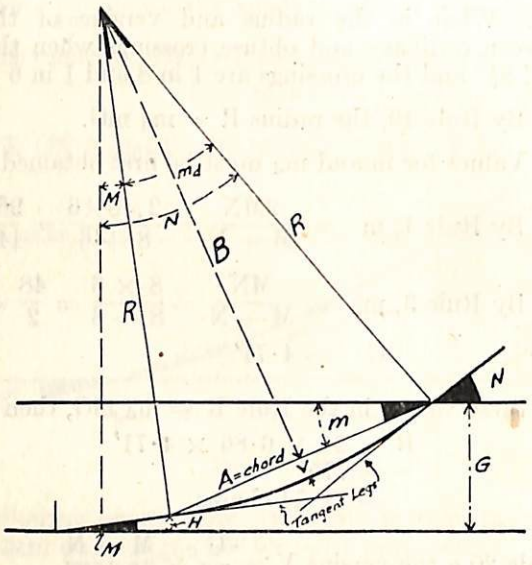


FIG. 126.

m_d = Difference between switch angle M and Crossing angle N

$$m_d = \frac{MN}{M - N} = \frac{32 \times 7}{32 - 7} = \frac{224}{25} = 8{\cdot}96$$

m = average of switch and crossing angles

$$m = \frac{2MN}{M + N} = \frac{2 \times 32 \times 7}{32 + 7} = \frac{448}{39} = 11{\cdot}49$$

$$G - H = 4'\ 8\tfrac{1}{2}'' - 4\tfrac{1}{2}'' = 4'\ 4'' = 4{\cdot}33'$$

then, by Rule 21,

$$R = 8{\cdot}96 \times 11{\cdot}49 \times 4{\cdot}33' = 446' = 6{\cdot}76 \text{ chains.}$$

Example (*b*).—What is the radius of the turnout curve for a "C" type REA switch with a 1 in 8 crossing, gauge 4′ 8½″ ?

From Table on p. 45 a "C" type REA switch has an equivalent angle of 1 in 22·68 = M, and the heel clearance $H = 10\frac{5}{16}'' = \cdot 86'$.

From Rule 21,

$$R = m_d\, m(G - H)$$

$$m_d = \frac{MN}{M - N} = \frac{22{\cdot}68 \times 8}{22{\cdot}68 - 8} = \frac{181{\cdot}44}{14{\cdot}68} = 12{\cdot}36$$

$$m = \frac{2\,MN}{M + N} = \frac{2 \times 22{\cdot}68 \times 8}{22{\cdot}68 + 8} = \frac{362{\cdot}88}{30{\cdot}68} = 11{\cdot}83$$

$$G - H = 4{\cdot}71' - {\cdot}86' = 3{\cdot}85'$$

Insert the above value for m_d, m, and (G — H) in Rule 21, then :—

$$R = 12{\cdot}36 \times 11{\cdot}83 \times 3{\cdot}85'$$
$$= 563' = 8{\cdot}53 \text{ chains.}$$

To obtain the versine of a turnout curve on a chord joining the switch heel and the intersection point of the crossing, (G — H) must be substituted for ' G ' in Rule 20a,

$$\text{i.e. } V = \frac{G - H}{4} \times \frac{M - N}{M + N} \qquad \textbf{(Rule 22)}$$

M being the switch angle and N the crossing angle.

Examples.—What are the versines for the turnout curves in Examples ' a ' and ' b ' on pp. 271 and 272 ?

(*a*) Insert the values for (G — H), M and N, in Rule 22, thus :—

$$V = \frac{4{\cdot}33}{4} \times \frac{32 - 7}{32 + 7}$$
$$= 1{\cdot}08 \times \frac{25}{39}$$
$$= {\cdot}69'$$
$$= 8\tfrac{1}{4}''$$

(*b*) Insert the values for (G — H), M and N in Rule 22, thus :—

$$V = \frac{3{\cdot}85}{4} \times \frac{22{\cdot}68 - 8}{22{\cdot}68 + 8}$$
$$= {\cdot}96 \times \frac{14{\cdot}68}{30{\cdot}68}$$
$$= {\cdot}46' = 5\tfrac{1}{2}''$$

RADIUS AND VERSINE OF TRACK CROSSING 6′ 5½″ OR OTHER SPACING 'S' BETWEEN TRACKS.

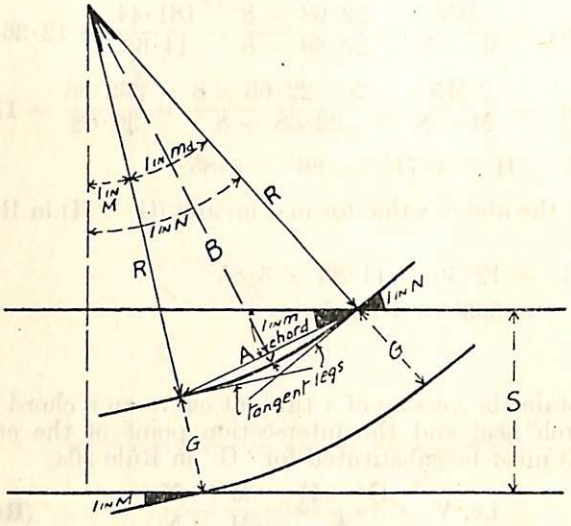


FIG. 127.

As in the case of track crossing the 4′ 8½″ way it is assumed that B = R.

By Rule 18, the chord length $A = m(S - G) + \frac{(S + G)}{4m}$

By Expression 2, $B = m_d A$

i.e. $R = m_d A$

$$= m_d \left(m(S - G) + \frac{(S + G)}{4m} \right)$$

$$= m_d\, m(S - G) + \frac{m_d(S + G)}{4m}$$

The tern $\frac{m_d(S + G)}{4m}$ is small in comparison with the radius and can be omitted, and then $R = m_d\, m(S - G)$. **(Rule 23)**

To obtain the versine, (S — G) must be substituted for 'G' in Rule 20a, thus :—

$$V = \frac{(S - G)}{4} \times \frac{M - N}{M + N} \qquad \textbf{(Rule 24)}$$

Examples (*a*).—What is the radius of track crossing a spacing of 7′ 6″ between running edges, gauge 4′ 8½″ with the crossing angles 1 in 12 and 1 in 10 ?

By Rule 23, $R = m_d\, m(S - G)$

First obtain the value of m

By Rule 1

$$m = \frac{2MN}{M+N} = \frac{2 \times 12 \times 10}{12 + 10} = \frac{240}{22} = 10{\cdot}91$$

By Rule 3,

$$m_d = \frac{MN}{M-N} = \frac{12 \times 10}{12 - 10} = \frac{120}{2} = 60$$

$$S - G = 7' 6'' - 4' 8\tfrac{1}{2}'' = 2' 9\tfrac{1}{2}'' = 2{\cdot}79'$$

Insert these values in Rule 23 thus :—

$$R = 60 \times 10{\cdot}91 \times 2{\cdot}79'$$
$$= 1826' = 27{\cdot}66 \text{ chains.}$$

(*b*) What is the versine of the above example ?

Insert the values for S — G, M and N in Rule 24, then

$$V = \frac{S-G}{4} \times \frac{M-N}{M+N}$$
$$= \frac{2{\cdot}79'}{4} \times \frac{12-10}{12+10}$$
$$= {\cdot}70' \times \frac{2}{22}$$
$$= {\cdot}06'' = \tfrac{3}{4}''$$

RADII AND VERSINE IN CASES WHERE A SHORT PIECE OF STRAIGHT IS INSERTED IN THE LEAD.

1. With short piece of straight at both crossings of track crossing 4′ 8½″ way.

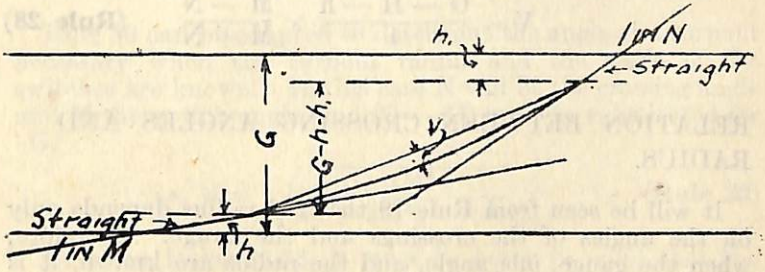


FIG. 128

If the track at the crossings is straight to points where the clearances are ' h ' and ' h_1 ' respectively then to obtain the Radius, substitute (G — h — h_1) for ' G ' in Rule 19, thus :—

$$R = m_d\, m(G - h - h_1) \qquad \textbf{(Rule 25)}$$

To obtain the Versine, substitute (G — h — h_1) for ' G ' in Rule 20a, thus :—

$$V = \frac{(G - h - h_1)}{4} \times \frac{M - N}{M + N} \qquad \textbf{(Rule 26)}$$

2. With short piece of straight at the crossing of a turnout.

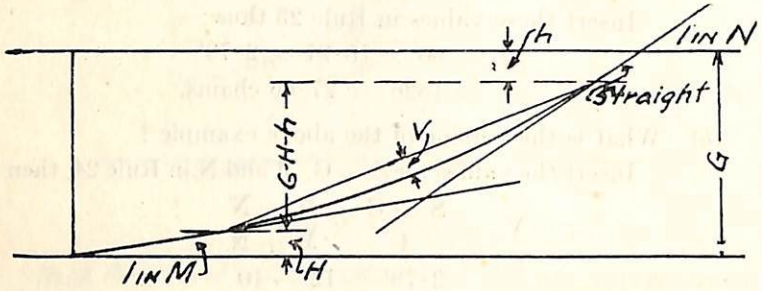


FIG. 129.

If the track at the crossing is straight to a point where the clearance is ' h ', then to obtain the Radius, substitute (G — H — h) for ' G ' in Rule 19, thus :—

$$R = m_d\, m(G - H - h) \qquad \textbf{(Rule 27)}$$

For the Versine, substitute (G — H — h) for ' G ' in Rule 20a, thus :—

$$V = \frac{G - H - h}{4} \times \frac{M - N}{M + N} \qquad \textbf{(Rule 28)}$$

RELATION BETWEEN CROSSING ANGLES AND RADIUS.

It will be seen from Rule 19 that the radius depends only on the angles of the crossings and the gauge. Therefore, when the gauge, one angle, and the radius are known, it is possible to determine the value of the other angle.

By Rule 19, $R = m_d\, mG$ for a track crossing the 4′ 8½″ way, between two crossings 1 in M and 1 in N.

$$\text{but} \quad m_d = \frac{MN}{M - N}$$

$$\text{and} \quad m = \frac{2MN}{M + N}$$

∴ Inserting these values in Rule 19 we have

$$R = \frac{MN}{M - N} \times \frac{2MN}{M + N} \times G$$

$$= \frac{2M^2N^2G}{M^2 - N^2}$$

$$\therefore \; RM^2 - RN^2 = 2M^2N^2G$$

$$\text{hence,} \; RM^2 - 2M^2N^2G = RN^2$$

$$\text{i.e.} \; M^2(R - 2N^2G) = RN^2$$

$$\therefore \; M^2 = \frac{RN^2}{R - 2N^2G}$$

$$\text{whence } M = \sqrt{\frac{RN^2}{R - 2N^2G}} \qquad \textbf{(Rule 29)}$$

and, therefore, if R and N are known M can be found.

Similarly if R and M are known it can be shown that

$$N = \sqrt{\frac{RM^2}{R + 2M^2G}} \qquad \textbf{(Rule 30)}$$

For a track crossing any space 'S' between tracks, by similar reasoning to the above, but using the rule $R = m_d m\,(S - G)$, we have

$$M = \sqrt{\frac{RN^2}{R - 2N^2(S - G)}} \qquad \textbf{(Rule 31)}$$

$$\text{and } N = \sqrt{\frac{RM^2}{R + 2M^2(S - G)}} \qquad \textbf{(Rule 32)}$$

Rule 30 can be adapted to determine the angle of a turnout necessary when the turnout radius and the angle of the switches are known. In this case N will be the crossing angle and M the switch angle, and (G — H) must be substituted for 'G,'

$$\text{i.e. } N = \sqrt{\frac{RM^2}{R + 2M^2(G - H)}} \qquad \textbf{(Rule 33)}$$

In using Rules 29-33, it must be borne in mind that the angle M is flatter than the angle N. Therefore if the sharper

angle is known Rule 29 or 31 must be used and if the flatter angle is known Rule 30 or 32 must be used. A sketch of the arrangement should always be used to determine whether the unknown crossing will be sharper or flatter than the known, or the following rule may be used for cases in which the main line is straight :—

Stand at the nose of the known crossing and look along the main line rail towards the other crossing. Then, if the turnout rail curves away from the main line rail the unknown crossing will be sharper than the known. If the turnout rail curves towards the main line rail then the unknown crossing will be flatter than the known.

Examples. (*a*)—In Fig. 113, if the angle M is a 1 in 8 crossing and the radius R is 900 ft. what will be the value of the angle N, when the gauge $= 4' 8\frac{1}{2}''$?

From the figure it will be seen that the angle N will be sharper than the angle M . · . by Rule 30

$$N = \sqrt{\frac{RM^2}{R + 2M^2G}}$$

Substituting the values of
$M = 8$, $R = 900'$, and $G = 4' 8\frac{1}{2}'' = 4{\cdot}71'$ in this,

$$\text{then } N = \sqrt{\frac{900 \times 8 \times 8}{900 + 2 \times 8 \times 8 \times 4{\cdot}71}}$$

$$= \sqrt{\frac{57600}{900 + 602{\cdot}88}}$$

$$= \sqrt{\frac{57600}{1502{\cdot}88}}$$

$$= \sqrt{38{\cdot}33}$$

$$= 6{\cdot}19$$

i.e. N = 1 in $6\frac{1}{4}$ nearly.

(*b*) In Fig. 120, if the angle N is 1 in 10 and the radius R = 1320 ft. what will be the value of the angle M if the space is $6' 5\frac{1}{2}''$?

From the figure it will be seen that the angle M will be flatter than the angle N therefore Rule 31 must be used.

$$\text{i.e. } M = \sqrt{\frac{RN^2}{R - 2N^2(S - G)}}$$

Inserting the values of R = 1320, N = 10 and S — G = 6′ 5½″ — 4′ 8½″ = 1′ 9″ = 1·75′ we have

$$M = \sqrt{\frac{1320 \times 10 \times 10}{1320 - 2 \times 10 \times 10 \times 1{\cdot}75}}$$

$$= \sqrt{\frac{132000}{970}}$$

$$= \sqrt{136{\cdot}08}$$

$$= 11{\cdot}66$$

$$= 1 \text{ in } 11\tfrac{3}{4} \text{ nearly.}$$

(*c*) What angle crossing should be used with 15 ft. switches, heel divergence 4½″, to give a turnout radius of 440 ft. when the gauge is 4′ 8½″ ?

Rule 33 must be used, i.e. the required angle

$$N = \sqrt{\frac{RM^2}{R + 2M^2(G - H)}}$$

In this case R = 440 ft.

G — H = 4′ 8½″ — 4½″ = 4′ 4″ = 4·33′

M = Switch angle = 40 from Table on p. 45.

Substituting these values in the rule we have

$$N = \sqrt{\frac{440 \times 40 \times 40}{440 + 2 \times 40 \times 40 \times 4{\cdot}33}}$$

$$= \sqrt{\frac{704000}{14296}}$$

$$= \sqrt{49{\cdot}24}$$

$$= 7{\cdot}017$$

i.e. N = 1 in 7

THE PRINCIPLE OF EQUIVALENT RADIUS.

All the rules obtained so far have been derived for cases in which the main lines are straight. Although not mathematically correct, it can be assumed without appreciable error that the lead of a turnout in a curved main will be the same as that of a turnout with the same type of switches and angle of crossing in a straight main.*

*The lead of a turnout in a curved main should be measured along the flatter curved rail on which the crossing lies. In some cases this may be the turnout rail.

Similarly the lead between crossings of a track crossing the 4′ 8½″ way or 6′ 5½″ or other space between tracks will be the same whether the main line is curved or straight, provided the angles of the crossings, and the gauge or space are the same.

The radius will, however, be different when the main is curved from that when the main is straight. When the radius of the main and the radius of the turnout are known, it is possible to calculate what the radius of the turnout would be if the main were straight, by the ' Principle of Equivalent Radius.'

The radius of the turnout, or track joining two crossings when the main is straight is known as the Equivalent Radius.

Let R = the Radius of the main line.
r = the Radius of the turnout in the curved main.
R_e = the Equivalent Radius of the turnout in a straight main.

Then, when the turnout and main are curves of similar flexure, i.e. are curved in the same direction, as in Fig. 130, and the radius of the main is greater than that of the turnout, i.e. the turnout is on the inside of the main,

$$R_e = \frac{R \times r}{R - r} \qquad \textbf{(Rule 34)}$$

When the turnout and main are of similar flexure and the turnout radius is greater than the main line radius, i.e. the turnout is on the outside of the curved main,

$$R_e = \frac{R \times r}{r - R} \qquad \textbf{(Rule 35)}$$

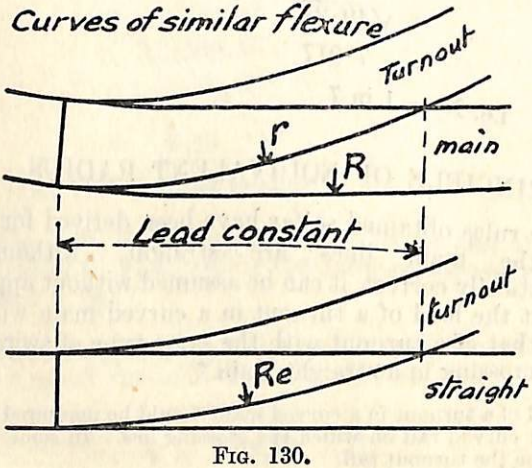


FIG. 130.

When the turnout and main are of contrary flexure, i.e. are curved in opposite directions as in Fig. 131,

$$R_e = \frac{R \times r}{R + r} \qquad \textbf{(Rule 36)}$$

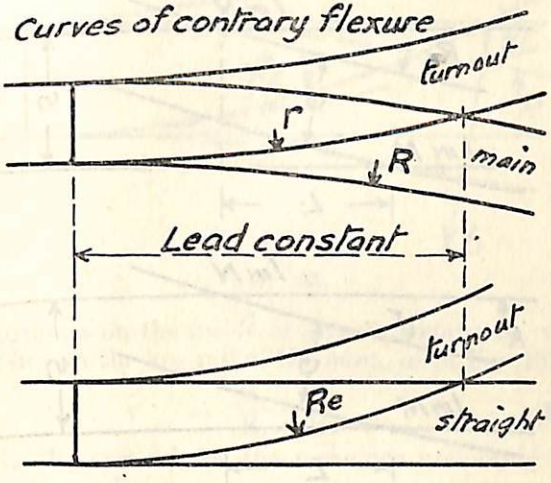


Fig. 131.

The above rules also apply to a track of radius ' r ' joining two crossings over the 4′ 8½″ way, or 6′ 5½″ or other space between tracks, when the main line radius is ' R '. In this case ' R_e' will be the radius of the track joining two crossings of the same angles across the same gauge or space when the main is straight, as shewn in Fig. 132.

Thus Rules 34 and 35 apply to the case shewn in Fig. 132a where the turnout and main are of similar flexure, and Rule 36 to the case shewn in Fig. 132c where the turnout and main are of contrary flexure.

It is, however, more often necessary to determine what the radius of a turnout would be in a curved main, when the equivalent radius of the turnout in a straight main is known.

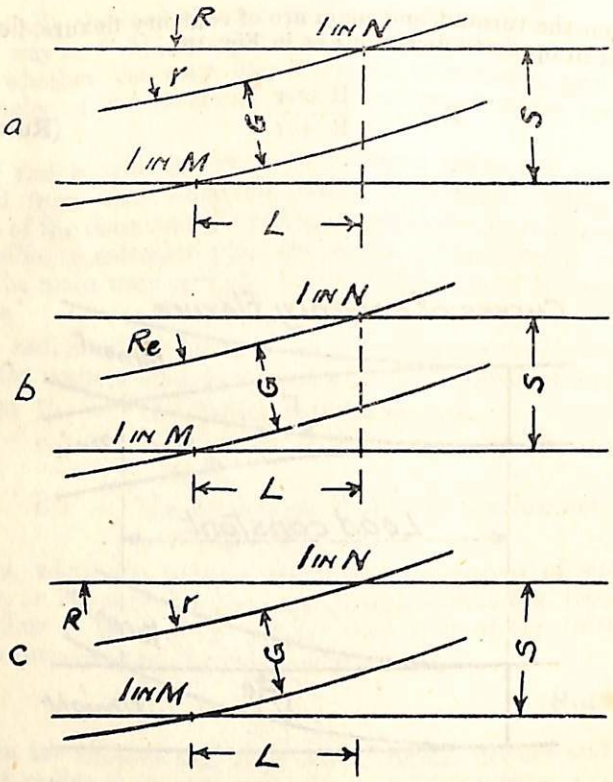


FIG. 132.

Fig. 133 shews a turnout from a straight main, and it will be seen that if the tracks are pulled in the direction 'a' as shewn by dotted lines, the radius of the turnout curve will be decreased, and the sharper the main line radius becomes the sharper also will become that of the turnout.

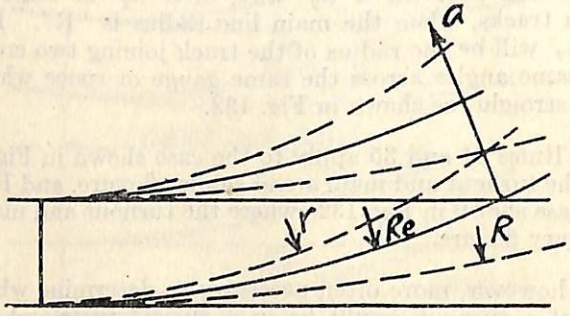


FIG. 133.

Similarly if the tracks are pulled in the direction 'b' as shewn by dotted lines in Fig. 134, the radius of the turnout will be increased as that of the main decreases. There will come a time when the turnout becomes straight, this being when $R = R_e$. When R is less than R_e, the turnout becomes curved in the same direction as the main.

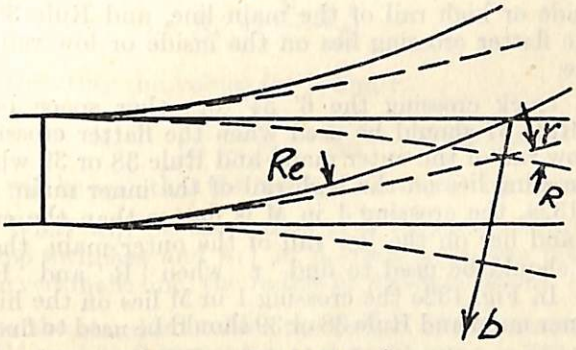


FIG. 134.

For turnouts on the inside of a curved main, i.e. when the crossing lies on the low rail of the main, as in Fig. 133,

$$r = \frac{R \times R_e}{R + R_e} \qquad \textbf{(Rule 37)}$$

where R_e, R, and r have the meanings previously ascribed to them.

For turnouts on the outside of a curved main, i.e. when the crossing lies on the high rail of the main, as in Fig. 134.

(1) if R is greater than R_e

$$r = \frac{R \times R_e}{R - R_e} \qquad \textbf{(Rule 38)}$$

and the turnout is curved in the opposite direction to the main.

(2) if R equals R_e then $r = \frac{R \times R_e}{0}$ and therefore r = infinity, i.e. the turnout is straight.

(3) if R is less than R_e

$$r = \frac{R \times R_e}{R_e - R} \qquad \textbf{(Rule 39)}$$

and the turnout is curved in the same direction as the main.

Rules 37, 38, and 39 also apply to a track joining two crossings over the 4′ 8½″ way or the 6′ 5½″ or other spacing

between tracks. Rule 37 should be used when the main line is curved in the same direction as the track joining the same two crossings would be in a straight main, and Rule 38 or 39 when the main line is curved in the opposite direction.

In practice this means that for a track crossing the 4′ 8½″ way Rule 37 should be used when the flatter crossing lies on the outside or high rail of the main line, and Rule 38 or 39 when the flatter crossing lies on the inside or low rail of the main line.

For a track crossing the 6′ 5½″ or other space between tracks, Rule 37 should be used when the flatter crossing lies on the low rail of the outer main, and Rule 38 or 39 when the flatter crossing lies on the high rail of the inner main. Thus in Fig. 132a, the crossing 1 in M is flatter than the crossing 1 in N, and lies on the low rail of the outer main, therefore Rule 37 should be used to find 'r' when 'R' and 'R_e' are known. In Fig. 132c the crossing 1 in M lies on the high rail of the inner main and Rule 38 or 39 should be used to find 'r'.

In this connection it should be noted that with straight mains, a track joining two crossings of the same angle will also be straight, and, therefore, from the above it follows that a track joining two crossings of the same angle, when the mains are curved, will be curved to the same radius, and in the same direction, as the curved mains.

The preceding rules give the same results in practice as the addition and subtraction of versines described on p. 245 *et seq.*

Examples.—(*a*) What is the equivalent radius from a straight track when the main line radius is 50 chains and the turnout radius is 12 chains, the curves being of similar flexure, (i.e. in the same direction) ?

$$\text{By Rule 34, } R_e = \frac{R \times r}{R - r}$$

Inserting the values for R and r then

$$R_e = \frac{50 \times 12}{50 - 12} = \frac{600}{38} = 15{\cdot}79 \text{ chs.} = 1{,}042 \text{ ft.}$$

(*b*) What would be the equivalent radius for Example (*a*) if the curves were of contrary flexure, i.e. in opposite directions ?

$$\text{By Rule 36, } R_e = \frac{R \times r}{R + r}$$

Insert the values of R and r then

$$R_e = \frac{50 \times 12}{50 + 12} = \frac{600}{62} = 9{\cdot}68 \text{ chs.} = 639 \text{ ft.}$$

(*c*) What would be the equivalent radius off the straight where the turnout radius is 50 chains and the main line radius is 12 chains, the curves being of similar flexure ?

In this case the turnout radius is greater than the main line radius. Rule 35 must, therefore, be used,

$$\text{i.e. } R_e = \frac{R \times r}{r - R}$$

Inserting the values for R and r,

$$R_e = \frac{12 \times 50}{50 - 12} = \frac{600}{38} = 15{\cdot}79 \text{ chs.} = 1{,}042 \text{ ft.}$$

It will be seen that the result is identical with Example (*a*).

(*d*) What will be the radius of a turnout comprising 'C' type switches and a 1 in 9 crossing on the inside of a curved main line, the radius of which is 50 chs. ?

From the standard tables the radius of the crossing curve of a 'C' — 1 in 9 turnout in a straight main is 740 ft. The main line radius = 50 chains = 3,300 ft. The crossing lies on the low rail of the main line, therefore by Rule 37

$$r = \frac{R \times R_e}{R + R_e}$$

Inserting the values of R and R_e

$$\text{then } r = \frac{3{,}300 \times 740}{3{,}300 + 740} = \frac{2{,}442{,}000}{4{,}040} = 604{\cdot}5 \text{ ft.}$$

(*e*) What would be the radius of the turnout in the above case if it were on the outside of the curved main ?

R will be 3,300 ft. and R_e will be 740 ft. as before, but in this case Rule 38 must be used, since R is greater than R_e.

$$\text{i.e. } r = \frac{R \times R_e}{R - R_e}$$

Inserting the values of R and R_e

$$\text{then } r = \frac{3{,}300 \times 740}{3{,}300 - 740} = \frac{2{,}442{,}000}{2{,}560} = 953{\cdot}9 \text{ ft.}$$

(*f*) What would be the radius of a track joining two crossings 1 in 8 to 1 in 7 across the 4′ 8½″ way of a main line of a radius of 1200 feet, the 1 in 8 crossing lying on the low rail of the main ?

R_e, i.e. the radius of the track joining a 1 in 8 to a 1 in 7 crossing across the 4′ 8½″ way of a straight main must first be obtained.

By Rule 19

$$R_e = m_d m G$$

$$\text{Now } m_d = \frac{M \times N}{M - N} = \frac{8 \times 7}{8 - 7} = 56$$

$$m = \frac{2MN}{M + N} = \frac{2 \times 8 \times 7}{8 + 7} = \frac{112}{15} = 7 \cdot 47$$

$$\text{and } G = 4' \, 8\tfrac{1}{2}'' = 4 \cdot 71'$$

$$\therefore R_e = 56 \times 7 \cdot 47 \times 4 \cdot 71 = 1{,}970 \text{ ft.}$$

In this case, therefore, R_e is greater than R, and as the main is curved in the opposite direction to the direction of the curve joining a 1 in 8 to a 1 in 7 crossing on a straight main Rule 39 must be used (*see* p. 284).

$$\text{i.e. } r = \frac{R \times R_e}{R_e - R}$$

Substituting the values of R and R_e

$$\text{then } r = \frac{1{,}200 \times 1{,}970}{1{,}970 - 1{,}200} = \frac{2{,}364{,}000}{770} = 3{,}070 \text{ ft.}$$

and the curve joining the two crossings will be in the same direction as the main line curve.

TURNOUTS FROM THE INSIDE OR OUTSIDE OF A CURVED MAIN LINE.

It is obvious that where turnouts are from the inside of a curved main the equivalent switch curve is sharpened, to an extent depending on the radius of the main line.

Fig. 135 shews a switch for a turnout from a straight main line. The switch curve is taken to be equivalent to the radius which would give a versine V_1 on a chord length equal to twice the switch length. From the Figure it will be seen that $V_1 = \frac{H}{2}$ where H is the heel offset.

Fig. 136 shews a switch from the inside of a curved main, V is the versine of the main line curve on a chord equal to twice the switch length. The equivalent switch radius has been decreased, as the versine V_2 on the same chord length equals $V + \frac{H}{2}$, i.e. the versine V_1 has been increased to V_2 by an amount equal to the versine V on the main line curve.

It will be seen from the above that, in order that the equivalent switch radius shall not be too sharp, a longer switch must be used when the turnout is from the inside of a curved main than would be used in a straight main.

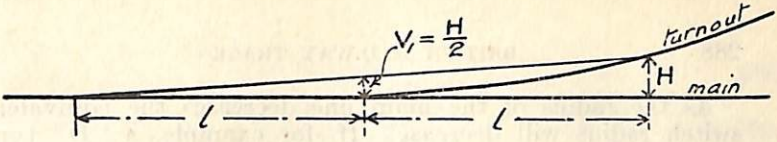


FIG. 135

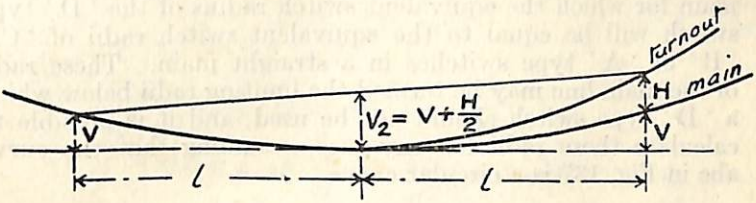


FIG. 136

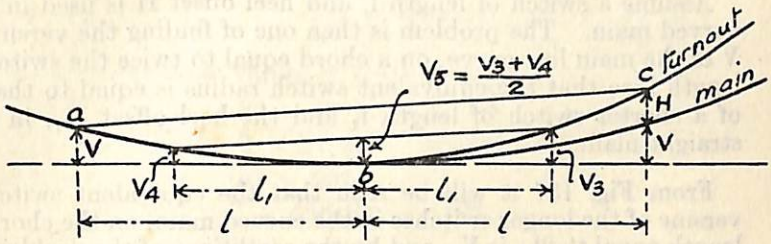


FIG. 137

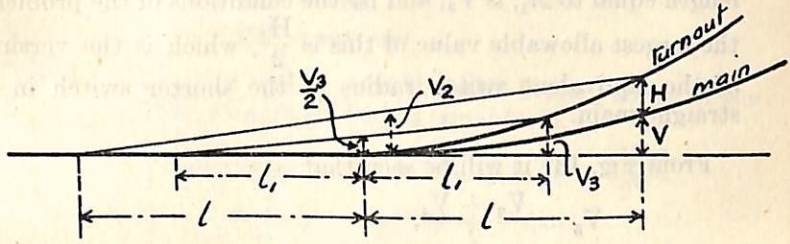


FIG. 138

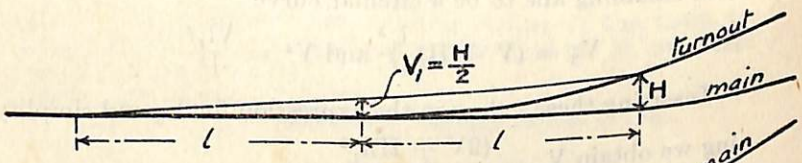


FIG. 139

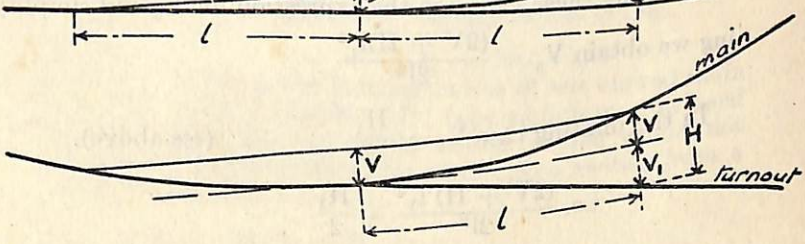


FIG. 140

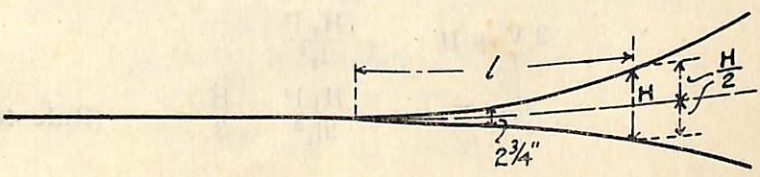


FIG. 141

As the radius of the main line decreases the equivalent switch radius will decrease. If, for example, a 'D' type switch is used in a curved main, there are certain radii of the main for which the equivalent switch radius of the 'D' type switch will be equal to the equivalent switch radii of 'C', 'B' or 'A' type switches in a straight main. These radii of the main line may be termed the limiting radii below which a 'D' type switch should not be used, and it is possible to calculate these radii for any case, assuming that the curve abc in Fig. 137 is a circular curve.

Assume a switch of length l, and heel offset H is used in a curved main. The problem is then one of finding the versine V of the main line curve, on a chord equal to twice the switch length l, so that the equivalent switch radius is equal to that of a shorter switch of length l_1 and the heel offset H_1, in a straight main.

From Fig. 137 it will be seen that the equivalent switch versine of the longer switches in the curved main, on the chord length equal to $2l_1$, is V_5, and by the conditions of the problem the largest allowable value of this is $\frac{H_1}{2}$, which is the versine of the equivalent switch radius of the shorter switch in a straight main.

From Fig. 137 it will be seen that

$$V_5 = \frac{V_3 + V_4}{2},$$

and assuming abc to be a circular curve

$$V_3 = (V + H)\frac{l_1^2}{l^2} \text{ and } V^4 = \frac{Vl_1^2}{l^2}$$

Inserting these values in the expression for V_5 and simplifying we obtain $V_5 = \frac{(2V + H)l_1^2}{2l^2}$

In the limiting case $V_5 = \frac{H_1}{2}$ (*see* above).

$$\text{i.e. } \frac{(2V + H)\, l_1^2}{2l^2} = \frac{H_1}{2}$$

$$2V + H = \frac{H_1 l^2}{l_1^2}$$

$$\therefore V = \frac{H_1 l^2}{2l_1^2} - \frac{H}{2} \qquad \textbf{(Rule 40)}$$

Example (*a*).—What is the limiting radius of the main line curve from the inside of which a ' D ' type switch may be used in order that the equivalent switch radius would not be greater than that given by a ' B ' type switch from a straight main line ?

$$\text{By Rule 40, } V = \frac{H_1 l^2}{2l_1^2} - \frac{H}{2}$$

From Table on p. 45, H for D type switch = ·81′
H_1 ,, B ,, ,, = ·83′
l ,, D ,, ,, = 31·58′
l_1 ,, B ,, ,, = 21·42′

Inserting these values in Rule 40, then

$$V = \frac{\cdot 83 \times 31\cdot 58 \times 31\cdot 58}{2 \times 21\cdot 42 \times 21\cdot 42} - \frac{\cdot 81}{2}$$

$$= \frac{\cdot 83 \times 997\cdot 3}{2 \times 458\cdot 82} - \cdot 405$$

$$= \cdot 902 - \cdot 405$$

$$= \cdot 497 \text{ or say } \cdot 50$$

From Fig. 137 it will be seen that this is the versine of the main line curve on a chord length equal to 2l.

∴ Inserting these values in the Rule $R = \frac{(\frac{1}{2}C)^2}{2V}$

we have $R = \frac{31\cdot 58^2}{2 \times \cdot 50} = \frac{997\cdot 3}{1}$

i.e. for ' D ' switches the limiting radius of the main to give an equivalent switch radius equal to that of ' B ' switches in a straight main is 997′.

Similarly for ' E ' switches the limiting radius is 732′.

Example (*b*).—What is the limiting radius of the curved main from the inside of which a ' D ' type switch may be used in order that the equivalent switch radius would not be greater than that given by a ' C ' type switch from a straight main line ?

In the rule $V = \frac{H_1 l^2}{2l_1^2} - \frac{H}{2}$

H_1 for ' C ' type switch = ·86′
H ,, ' D ' ,, ,, = ·81′
l_1 ,, ' C ' ,, ,, = 27·42′
l ,, ' D ' ,, ,, = 31·58′

Inserting these values in the above rule

$$V = \frac{\cdot 86 \times 31 \cdot 58^2}{2 \times 27 \cdot 42^2} - \frac{\cdot 81}{2}$$

$$= \frac{\cdot 86 \times 997 \cdot 3}{2 \times 751 \cdot 86} - \cdot 405$$

$$= \frac{857 \cdot 68}{1{,}503 \cdot 71} - \cdot 405$$

$$= \cdot 570 - \cdot 405$$

$$= \cdot 165'$$

Now as $R = \frac{(\frac{1}{2}C)^2}{2V}$ the limiting radius for D switch

$$= \frac{31 \cdot 58^2}{2 \times \cdot 165}$$

$$= 3{,}022'$$

Similarly for 'E' switch the limiting radius is 1,433'
and for 'F' ,, ,, ,, ,, 1,112'

Where the main line curve commences at the tip of the switch as shewn in Fig. 138, the versine of the equivalent switch radius becomes $\frac{V + H}{2}$. Thus the versine V_3 is reduced by an amount equal to $\frac{V}{2}$ when the main line is straight up to the tip of the switch. The versine V_5 for the limiting curve will become $\frac{V_3}{2}$. It has been shewn, however, that $V_3 = (V + H)\frac{l_1^2}{l^2}$, and therefore

$$V_5 = \frac{(V + H)l_1^2}{2l^2}$$

If, therefore, it is required that the equivalent switch versine shall not be greater than that of a switch of length l_1 and heel offset H_1 in a straight main, the largest allowable value of V_5 is $\frac{H_1}{2}$. Therefore, in the limiting case

$$\frac{(V + H)l_1^2}{2l^2} = V_5 = \frac{H_1}{2}$$

$$\therefore V = \frac{H_1 l^2}{l_1^2} - H$$

Where the main line curve commences at the heel of the switch as in Fig. 139, the equivalent switch radius is identical with that shewn in Fig. 135, i.e. $V_1 = \frac{H}{2}$, though the turnout radius will be affected as shewn on pp. 281-283.

Where the turnout is from the outside of a curved main line, the equivalent switch radius is increased, and the versine V_1 of such a radius is equal to the heel offset H minus the versine V of the main line curve on a chord length equal to twice the switch length l, i.e. $V_1 = H - V$. (*See* Fig. 140).

Where the main line is straight up to the tip of the switch, curving in either direction therefrom, the switch diversion can be halved by bending both stock rails to a line bisecting the switch clearance as shewn in Fig. 141, and making the switch symmetrical about this line.

CHAPTER X.

DESIGN OF LAYOUTS.

(By use of Formulæ based on Unit Angle of Switches and Crossings).

In this Chapter, the rules which were derived in Chapter IX will be applied to the design of a number of types of layouts in common use.

CROSSOVER ROAD.

This is the name given to a connection between two lines, consisting of two turnouts with a length of track connecting them across the space between the two lines, as shewn in Fig. 142.

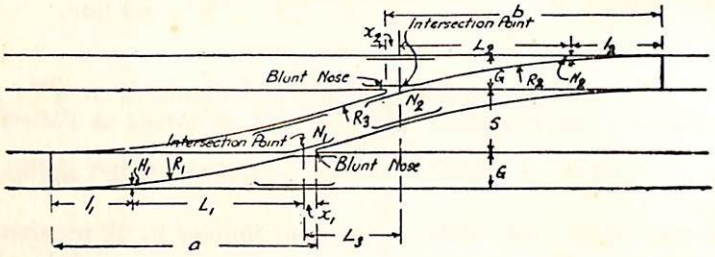


FIG. 142. CROSSOVER ROAD.

When the angles of the crossings N_1 and N_2 are decided upon the leads marked 'a' and 'b' may be taken from standard tables, or, alternatively, the leads L_1 and L_2 may be calculated from Rule 11. In this case

$$a = l_1 + L_1 + x_1$$
$$\text{and } b = l_2 + L_2 + x_2$$

where l_1 and l_2 are the switch lengths of the two switches, and x_1 and x_2 are the distances from intersection point to blunt nose of the two crossings.

The lead L_3 can be calculated from Rule 17, and the radii R_1 and R_2 can be calculated from Rule 21. The radius R_3 of the track joining the two crossings can be calculated from Rule 23.

The overall length of the crossover from tip of switches to tip of switches

$$= a + b + L_3 - x_1 - x_2$$
$$\text{or } = l_1 + L_1 + L_3 + L_2 + l_2$$

Where the crossings N_1 and N_2 are of the same angle the crossover road is symmetrical and a = b. The lead L_3 can be calculated from Rule 15. In this case, when the main lines are straight, the track joining the two crossings will be straight also, and when the main lines are curved, it will be curved to the same radius as the main lines.

SCISSORS CROSSOVER ROADS.

When two crossover roads between two main lines cross each other the arrangement is known as ' scissors ' crossovers. Fig. 144 and 148 shew details of two types of symmetrical arrangements, *i.e.* with the switches in the two mains opposite, and the turnout crossings all of the same angle. Cases of unsymmetrical scissors crossover roads are frequently met in practice, but the calculations for the leads and angles can generally be dealt with in a similar manner to those for symmetrical scissors, which will be explained in the following pages.

Case 1. Tracks straight across space between mains.

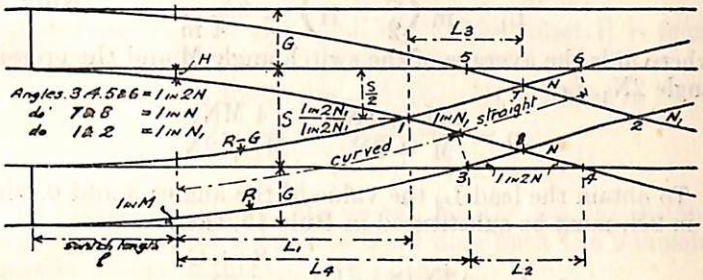


FIG. 143. SCISSORS CROSSOVERS.

In Fig. 143 the turnout angles are numbered 3, 4, 5 and 6, and the values of these are the same, as the crossovers are symmetrical, and are called for convenience 1 in 2N. The tracks are straight between these crossings and, therefore, the angle of the diamonds 7 and 8 will be one half of the turnout angles, *i.e.* the diamond angle is 1 in N.

Crossings Nos. 1 and 2, are common crossings of angle 1 in N_1 as marked in the figure, and, as they lie on the lead curves, they will be flatter than 1 in N. Also as the scissors are symmetrical their intersection points will lie on the centre line of the space between the tracks. This centre line will divide each of the crossings Nos. 1 and 2 into two equal angles of 1 in $2N_1$.

When the angles of the crossings 3, 4, 5, and 6, and the type of switches are decided upon the lead L_4 and the radius R

can either be taken from standard tables or calculated by Rules 11 and 21. It then remains to find the angle N_1 of the crossings 1 and 2, and the leads L_1, L_2 and L_3.

The angle $2N_1$ can be obtained by Rule 33, as from Fig. 143, it will be seen that the problem is one of finding the angle of a turnout of radius R — G, with a gauge of S/2, and a switch angle l in M.

Substituting these values in Rule 33 the following Rule is obtained

$$2N_1 = \sqrt{\frac{(R - G)\,M^2}{(R - G) + 2M^2\left(\frac{S}{2} - H\right)}} \quad \textbf{(Rule 41)}$$

from which N_1 can be obtained.

To obtain the Lead L_1 the gauge $\frac{S}{2}$ must be substituted in Rule 11, *i.e.*

$$L_1 = m\left(\frac{S}{2} - H\right) - \frac{\frac{S}{2} - H}{4\,m}, \quad \textbf{(Rule 42)}$$

where m is the average of the switch angle M and the crossing angle $2N_1$, *i.e.*

$$m = \frac{2M \times 2N_1}{M + 2N_1} = \frac{4\,MN_1}{M + 2N_1}$$

To obtain the lead L_2 the value of the angles 3 and 6, viz. : 1 in 2N, must be substituted in Rule 15, then

$$L_2 = 2N\,(S - G) - \frac{S + G}{8N}$$

From Fig. 143 it will be seen that

$$L_3 = L_4 + \frac{L_2}{2} - L_1$$

Example.

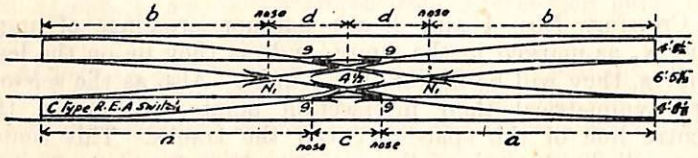


FIG. 144. SCISSORS CROSSOVERS.

Fig. 144 shews a symmetrical crossover road comprising turnouts with REA 'C' type switches and 1 in 9 crossings, with straight track across the 6 ft. space.

It is required to find the dimensions marked a, b, c, and d in the figure and the angle of the crossing N_1.

The length of the lead and the crossing radius of the turnout must be obtained before the angle of the crossing N_1 can be found. If tables are available the information can be taken therefrom.

From Table 5 p. 58 we find :

Lead a = 77′ $7\frac{1}{4}$″
Radius R = 740′

In this case, however, the lead and radius will be calculated.

By Rule 11a the lead from heel of switch to intersection point of crossing is

$$L = m\,(G - H)$$

In this rule m is the average of the switch and crossing angles.

From Table 1 the angle of an REA 'C' type switch is 22·68, and the angle of the crossings is 1 in 9.

$$\therefore\ m = \frac{2\,MN}{M + N} = \frac{2 \times 22{\cdot}68 \times 9}{22{\cdot}68 + 9} = \frac{408{\cdot}24}{31{\cdot}68} = 12{\cdot}89$$

Also from Table 1 the value of the heel offset H is found to be $10\frac{5}{16}$″ = ·86′ ∴ G — H = 4·71′ — ·86′ = 3·85′.

Inserting these values of m and (G — H) in Rule 11a

$$L = 12{\cdot}89 \times 3{\cdot}85$$
$$= 49{\cdot}63'$$
$$= 49'\ 7\tfrac{1}{2}''$$

To obtain the lead a, the switch length, and the distance from the intersection point to blunt nose for a 1 in 9 crossing must be added to this value of L, thus :—

Lead L, switch heel to intersection point of crossing	= 49′ $7\frac{1}{2}$″
Switch length, tip to heel of switches (*see* Table 1)	= 27′ 5″
Intersection point to blunt nose of 1 in 9 crossing = 9 × $\frac{3}{4}$″	= $6\frac{3}{4}$″
Lead 'a'	= 77′ $7\frac{1}{4}$″

By Rule 21, $R = m_d\,m(G - H)$

in which m_d is the difference of the switch and crossing angles,

i.e. $m_d = \dfrac{MN}{M - N}$

Inserting the values of M and N previously given

$$m_d = \frac{22{\cdot}68 \times 9}{22{\cdot}68 - 9} = \frac{204{\cdot}12}{13{\cdot}68} = 14{\cdot}92$$

As previously found m = 12·89 and G — H = 3·85′

$$\therefore\ R = 14{\cdot}92 \times 12{\cdot}89 \times 3{\cdot}85'$$
$$= 740'$$

The Unit Angle of the Crossing N_1 can be obtained from Rule 41, *i.e.*

$$2N_1 = \sqrt{\frac{(R - G\,M^2}{(R - G) + 2M^2\left(\frac{S}{2} - H\right)}}$$

In this rule R = 740′, G = 4′ 8½″ = 4·71′, therefore R — G = 740′ — 4·71′ = 735·29′.

Also $\frac{S}{2} = \frac{6'\ 5\frac{1}{2}''}{2} = \frac{6{\cdot}46'}{2} = 3{\cdot}23'$ and H = ·86′ as before

$$\therefore \frac{S}{2} - H = 3{\cdot}23' - {\cdot}86' = 2{\cdot}37'$$

Inserting these values in the rule

$$2N_1 = \sqrt{\frac{735{\cdot}29 \times 22{\cdot}68 \times 22{\cdot}68}{735{\cdot}29 + 2 \times 22{\cdot}68 \times 22{\cdot}68 \times 2{\cdot}37}}$$

$$= \sqrt{\frac{378219}{735{\cdot}29 + 2438{\cdot}16}}$$

$$= \sqrt{\frac{378219}{3173{\cdot}45}}$$

$$= \sqrt{119{\cdot}18}$$

$$= 10{\cdot}92$$

$$\therefore N_1 = 5{\cdot}46$$

i.e. the crossing N_1 is 1 in 5½ nearly.

The lead L_1 in Fig. 143, can be obtained from Rule 42, *i.e.*

$$L_1 = m\left(\frac{S}{2} - H\right) - \frac{\frac{S}{2} - H}{4m}$$

'm' in this case is the average of the switch crossing M and half the angle of the Crossing N_1

$$= \frac{4MN_1}{M + 2N_1}$$ as explained on p. 294.

Now M = 22·68 and $N_1 = 5{\cdot}46$

$$\therefore m = \frac{4 \times 22{\cdot}68 \times 5{\cdot}46}{22{\cdot}68 + 10{\cdot}92}$$

$$= \frac{495{\cdot}33}{33{\cdot}60}$$

$$= 14{\cdot}74$$

Inserting this, and the value of $\frac{S}{2}$ — H previously found we have

$$\begin{aligned} L_1 &= 14{\cdot}74 \times 2{\cdot}37 - \frac{2{\cdot}37}{58{\cdot}96} \\ &= 34{\cdot}93 - {\cdot}04 \\ &= 34{\cdot}89 \\ &= 34' \ 10\tfrac{5}{8}'' \end{aligned}$$

From Fig. 144, it will be seen that to obtain the dimension 'b' we must add to this value of L_1 the distance from tip to heel of switches, and deduct from the sum the distance from intersection point to blunt nose, thus

L_1 = ...	34′	$10\frac{5}{8}''$
Switch length for 'C' type switches ..	27′	5″
	62′	$3\frac{5}{8}''$
Distance from intersection to blunt nose of 1 in $5\frac{1}{2}$ crossing = $5\frac{1}{2} \times \frac{3}{4}''$		$4\frac{1}{8}''$
Dimension 'b' = ..	61′	$11\frac{1}{2}''$

The dimension 'c' is obtained from the lead L between crossings of angle N across a space S between tracks.

By Rule 15,

$$L = N\,(S - G) - \frac{S + G}{4N}$$

Inserting the values for N, S and G then

$$\begin{aligned} L &= 9\,(6'\ 5\tfrac{1}{2}'' - 4'\ 8\tfrac{1}{2}'') - \frac{6'\ 5\frac{1}{2}'' + 4'\ 8\frac{1}{2}''}{4 \times 9} \\ &= 9\,(1{\cdot}75) - \frac{11{\cdot}17}{36} \\ &= 15{\cdot}75 - {\cdot}31 \\ &= 15{\cdot}44 = 15'\ 5\tfrac{1}{4}'' \end{aligned}$$

This distance L is to the intersection points of the crossings, and, therefore, to obtain the dimension 'c' the distance from intersection to blunt nose of each crossing must be deducted :—

L	= 15′	$5\frac{1}{4}''$
2 × Distance intersection to blunt nose for 1 in 9 crossing = $2 \times 9 \times \frac{3}{4}''$ =	1′	$1\frac{1}{2}''$
Dimension 'c'	= 14′	$3\frac{3}{4}''$

As the scissors crossovers are symmetrical, the diamond crossings lie on a line halfway between the two ordinary crossings, *i.e.* half the distance ' c ' from either crossing.

The distance ' d ' therefore

$$= a + \frac{c}{2} - b$$

$$= 77' \ 7\tfrac{1}{4}'' + \frac{14' \ 3\tfrac{3}{4}''}{2} - 61' \ 11\tfrac{1}{2}''$$

$$= 22' \ 9\tfrac{5}{8}''$$

The required dimensions are therefore :—

a = 77′ 7¼″
b = 61′ 11½″
c = 14′ 3¾″
d = 22′ 9⅝″
N = 5½

Case 2. Tracks straight through the diamond.

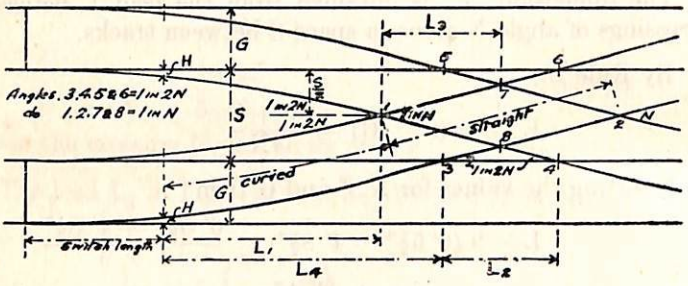


FIG. 145. SCISSORS CROSSOVERS.

In the above figure the turnout crossings are numbered 3, 4, 5, and 6, and the crossings of the diamond 1, 2, 7, and 8. The angle of the crossings 3, 4, 5, and 6 is for convenience taken as 1 in 2N, and as the track is straight between crossings 1 and 2, it will be seen that the angles of the crossings 1, 2, 7, and 8 will all be equal to 1 in N.

As the scissors is symmetrical the intersection point of crossings Nos. 1 and 2 will lie on the centre line of the track spacing, *i.e.* at a distance of $\frac{S}{2}$ from the running edge of each rail, this centre line will then cut each crossing into equal angles 1 in 2N.

From the figure it will be seen that the lead L_1 from the heel of the switches to crossing No. 1 will be that of a turnout with switches of an angle 1 in M, when the gauge equals $\frac{S}{2}$ and the crossing angle is 2N.

Substituting the value of $\frac{S}{2}$ for the gauge in Rule 11 we have

$$L_1 = m\left(\frac{S}{2} - H\right) - \frac{\frac{S}{2} - H}{4m} \qquad \textbf{(Rule 43)}$$

where H is the heel offset of the switches and m is the average of the switch angle M and the crossing angle 2N, *i.e.*

$$m = \frac{2 \times M \times 2N}{M + 2N} = \frac{4\,MN}{M + 2N}$$

To obtain the lead L_2 the value of the angles of the crossings 3 and 6 must be substituted in Rule 15, thus

$$L_2 = 2N\,(S - G) - \frac{S + G}{8N}$$

Fig. 146 is an enlarged diagram shewing crossings 1, 2, 7 and 8.

By comparison with Fig. 145, it will be seen that $L_3 = B$, and as previously explained $B = NA$, therefore $L_3 = NA$.

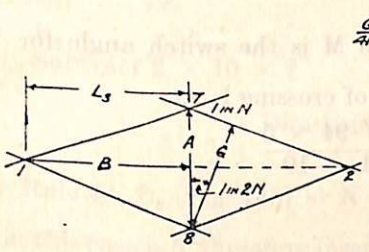


Fig. 146.

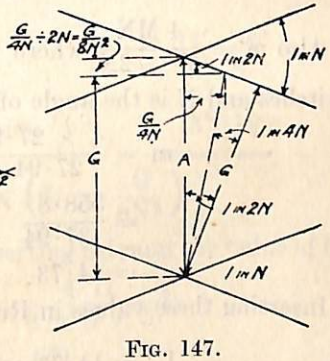


Fig. 147.

Enlarged Details of Diamond Crossing.

From Fig. 147, it will be seen that A exceeds the gauge by an amount equal to $\frac{G}{8N^2}$, therefore $A = G + \frac{G}{8N^2}$

hence $Z_3 = N\left(G + \frac{G}{8N^2}\right) = NG + \frac{G}{8N}$ **(Rule 44)**

From Fig. 145, it will be seen that

$$L_4 = L_1 + L_3 - \frac{L_2}{2}$$

Example.

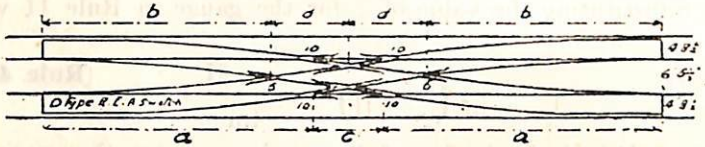


FIG. 148. SCISSORS CROSSOVERS.

Obtain the dimensions marked 'a', 'b', 'c', and 'd' in Fig. 148, when the turnout angles are 1 in 10 and the switches are REA 'D' type.

$$\text{By Rule 43, } L_1 = m\left(\frac{S}{2} - H\right) - \frac{\left(\frac{S}{2} - H\right)}{4m}$$

$$\text{Now } \frac{S}{2} = \frac{6'\ 5\frac{1}{2}''}{2} = \frac{6 \cdot 46'}{2} = 3 \cdot 23'$$

$$\text{H for 'D' switch} = 9\tfrac{47}{64}'' = \cdot 81'$$

$$\text{therefore } \frac{S}{2} - H = 2 \cdot 42'$$

Also $m = \frac{4\,MN}{M + 2N}$ where M is the switch angle for 'D' switches and N is the angle of crossing l., *i.e.*

$$m = \frac{4 \times 27 \cdot 94 \times 5}{27 \cdot 94 + 10}$$

$$= \frac{558 \cdot 8}{37 \cdot 94}$$

$$= 14 \cdot 73$$

Inserting these values in Rule 43

$$L_1 = 14 \cdot 73 \times 2 \cdot 42 - \frac{2 \cdot 42}{58 \cdot 92}$$

$$= 35 \cdot 65 - \cdot 04$$

$$= 35 \cdot 61$$

$$= 35'\ 7\tfrac{3}{8}''$$

The switch length must be added to this value of L_1, and the distance intersection to blunt nose of a 1 in 5 crossing subtracted from the sum, to give the dimension 'b'.

Thus, L_1	=	35′ $7\frac{3}{8}$″
Add switch length for ' D ' switches	=	31′ 7″
		67′ $2\frac{3}{8}$″
Subtract $5 \times \frac{3}{4}$″ ..	=	$3\frac{3}{4}$″
Dimension ' b '	=	66′ $10\frac{5}{8}$″

From p. 299

$$L_2 = 2N\,(S - G) - \frac{S + G}{8N}$$

where $N = 5$.

Inserting this value and those of S and G we have

$$L_2 = 10\,(6'\ 5\tfrac{1}{2}'' - 4'\ 8\tfrac{1}{2}'') - \frac{6'\ 5\frac{1}{2}'' + 4'\ 8\frac{1}{2}''}{8 \times 5}$$

$$= 10\,(1{\cdot}75) - \frac{11{\cdot}17}{40}$$

$$= 17{\cdot}5 - {\cdot}28$$

$$= 17{\cdot}22'$$

$$= 17'\ 2\tfrac{5}{8}'' = L_2 \text{ in Fig. 145.}$$

This distance L_2 is to the intersection points of the crossings. Consequently the distance intersection to blunt nose for two 1 in 10 crossings must be deducted therefrom to obtain dimension ' c ', *i.e.*

L_2	=	17′ $2\frac{5}{8}$″
Subtract $2 \times 10 \times \frac{3}{4}$″ ..	=	1′ 3″
Dimension ' c '	=	15′ $11\frac{5}{8}$″

By Rule 44, L_3 (Fig. 145) $= N\left(G + \frac{G}{8N^2}\right)$

N in this case is 5, therefore inserting this and the value of G,

$$L_3 = 5 \times \left(4{\cdot}71 + \frac{4{\cdot}71}{8 \times 5 \times 5}\right)$$

$$= 5 \times (4{\cdot}71 + {\cdot}02)$$

$$= 5 \times 4{\cdot}73$$

$$= 23{\cdot}65$$

$$= 23'\ 7\tfrac{3}{4}''$$

The lead L_3 is to the intersection point of the crossing, and the distance intersection to blunt nose for a 1 in 5 crossing must be added thereto to give dimension ' d '.

Thus, L_3	=	23′ $7\frac{3}{4}$″
Add $5 \times \frac{3}{4}$″ ..	=	$3\frac{3}{4}$″
Dimension ‘ d ’	=	23′ $11\frac{1}{2}$″

The lead L_4 (Fig. 145) $= L_1 + L_3 - \frac{L_2}{2}$

Inserting the values of L_1, L_2 and L_3 obtained above

$$L_4 = 35' \; 7\tfrac{3}{8}'' + 23' \; 7\tfrac{3}{4}'' - \frac{17' \; 2\tfrac{5}{8}''}{2}$$
$$= 59' \; 3\tfrac{1}{8}'' - 8' \; 7\tfrac{5}{16}''$$
$$= 50' \; 7\tfrac{13}{16}''.$$

L_4 being from heel of switch to intersection point of crossing, the switch length and distance from intersection to blunt nose must be added thereto to obtain dimension ‘ a ’

L_4	=	50′ $7\frac{13}{16}$″
Switch length for ‘ D ’ switches	..	31′ 7″
$10 \times \frac{3}{4}$″	=	$7\frac{1}{2}$″
Dimension ‘ a ’	..	82′ $10\frac{5}{16}$″

This dimension can be obtained direct from the distances b, c, and d, as from Fig. 148 it will be seen that $a = b + d - \frac{c}{2}$

i.e. $a = 66' \; 10\frac{5}{8}'' + 23' \; 11\frac{1}{2}'' - \frac{15' \; 11\frac{5}{8}''}{2} = 82' \; 10\frac{5}{16}''$

The required dimensions are thus :

$a = 82' \; 10\frac{5}{16}''$
$b = 66' \; 10\frac{5}{8}''$
$c = 15' \; 11\frac{5}{8}''$
$d = 23' \; 11\frac{1}{2}''$

DOUBLE LINE JUNCTION WITH CIRCULAR CURVE.

Double line junctions are generally designed by the use of trigonometry, but the principles and rules given in the previous Chapter can be utilised for such designs.

Fig. 149 is a diagram of a double line junction, the crossings being numbered 1-6 inclusive. The Crossings marked 1 and 2 are of the same angle. Similarly those marked 4 and 5 are of the same angle.

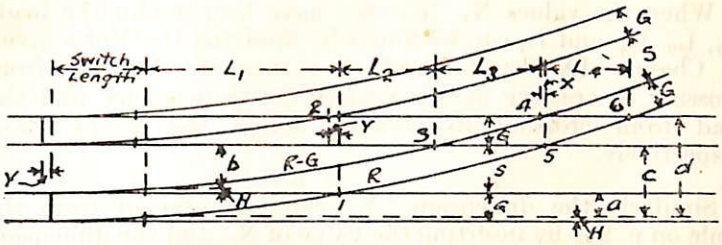


FIG. 149. DOUBLE LINE JUNCTION.

The information that has to be obtained, when the junction radius is given, is the angles of the crossings 1 to 6, the length of the Leads L_1, L_2, L_3, and L_4, the lead of the switches 'Y' and the lead of the diamonds 'X'.

R = Radius of junction curve of outer rail.
M = Equivalent switch angle.
H = Heel offset.
N_1, N_2, — N_6 = Angles of crossings.
G = Gauge of track.
S = Space between tracks.

Then from Fig. 149.

$a = G - H$
$b = S - H$
$c = S + G - H$
$d = S + 2G - H$

The value of N_1 can be found from Rule 30 by substituting 'a' for 'G' in the rule :

$$\text{Thus } N_1 = \sqrt{\frac{RM^2}{R + 2M^2a}} = N_2 \text{ (}see\text{ p. 302).}$$

The value of N_3 can be obtained by substituting 'R — G' for 'R' and 'b' for 'G' in the same rule :

$$\text{Thus } N_3 = \sqrt{\frac{(R - G)\,M^2}{(R - G) + 2M^2b}}$$

Similarly to obtain the values of N_5 and N_4 substitute 'c' for 'G' in the same rule :

$$\text{Thus } N_5 = \sqrt{\frac{RM^2}{R + 2M^2c}} = N_4 \text{ (}see\text{ p. 302),}$$

and for the value of N_6 substitute 'd' for 'G' in the rule :

$$\text{Thus } N_6 = \sqrt{\frac{RM^2}{R + 2M^2d}}$$

When the values N_1, N_2, etc., have been found the leads L_1, L_2, L_3, and L_4 can be found by applying the Rules given in Chapter IX for the lead of a turnout, the lead from crossing to crossing across a space between tracks, and the lead from crossing to crossing across the 4′ 8½″ way respectively.

Similarly the dimension 'Y' can be obtained from the Rule on p. 241 by inserting the value of N_1, and the dimension 'X' can be obtained from the Rule on p. 240 by inserting the value of N_4.

Example.

What are the angles and leads for a double line junction of radius 740 ft., with a standard six-foot space, using 'C' type switches ?

Referring to Fig. 149,

$R = 740$, whence $R - G = 740 - 4{\cdot}71 = 735{\cdot}29$

$H = {\cdot}86$ (*see* Table 1)

$a = G - H = 4{\cdot}71 - {\cdot}86 = 3{\cdot}85.$

$b = S - H = 6{\cdot}46 - {\cdot}86 = 5{\cdot}60.$

$c = S + G - H = 6{\cdot}46 + 4{\cdot}71 - {\cdot}86 = 10{\cdot}31.$

$d = S + 2G - H = 6{\cdot}46 + 9{\cdot}42 - {\cdot}86 = 15{\cdot}02.$

$M = 22{\cdot}68.$ (*see* Table 1)

Inserting the appropriate values in the Rule

$$N_1 = \sqrt{\frac{RM^2}{R + 2M^2a}}, \text{ we have}$$

$$N_1 = \sqrt{\frac{740 \times 22{\cdot}68 \times 22{\cdot}68}{740 + 2 \times 22{\cdot}68 \times 22{\cdot}68 \times 3{\cdot}85}}$$

$$= \sqrt{\frac{380641}{740 + 3960{\cdot}73}}$$

$$= \sqrt{\frac{380641}{4700{\cdot}73}}$$

$$= \sqrt{80{\cdot}97}$$

$= 8{\cdot}99$, and this is also the value of N_2.

$$\text{Similarly } N_3 = \sqrt{\frac{(R - G)\,M^2}{R - G + 2M^2b}}$$

$$= \sqrt{\frac{735{\cdot}29 \times 22{\cdot}68 \times 22{\cdot}68}{735{\cdot}29 + 2 \times 514{\cdot}38 \times 5{\cdot}6}}$$

$$= \sqrt{\frac{378218{\cdot}47}{6496{\cdot}35}}$$

$$= \sqrt{58{\cdot}22}$$

$$= 7{\cdot}63$$

$$N_4 = N_5 = \sqrt{\frac{RM^2}{R + 2M^2c}}$$

$$= \sqrt{\frac{740 \times 22{\cdot}68 \times 22{\cdot}68}{740 + 2 \times 22{\cdot}68 \times 22{\cdot}68 \times 10{\cdot}31}}$$

$$= \sqrt{\frac{380641}{11346}}$$

$$= \sqrt{33{\cdot}55}$$

$$= 5{\cdot}79$$

$$\text{and } N_6 = \sqrt{\frac{RM^2}{R + 2M^2d}}$$

$$= \sqrt{\frac{380641}{740 + 2 \times 22{\cdot}68 \times 22{\cdot}68 \times 15{\cdot}02}}$$

$$= \sqrt{\frac{380641}{16191{\cdot}97}}$$

$$= \sqrt{23{\cdot}51}$$

$$= 4{\cdot}85$$

Thus the angles of the junction crossings are as follows :—

N_1	N_2	N_3	N_4	N_5	N_6
8·99	8·99	7·63	5·79	5·79	4·85

Assuming that standard crossings are supplied in $\frac{1}{4}$ units, the angles would be made as follows :—

N_1	N_2	N_3	N_4	N_5	N_6
9	9	$7\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	5

This would have the effect of making the radius slightly different from 740 feet.

The leads will be found using the latter angles :—

By Rule 11a, $L_1 = m(G - H)$, where m in the average of the two angles 22·68 and 9

$$\text{whence } m = \frac{2 \times 22{\cdot}68 \times 9}{22{\cdot}68 + 9} = 12{\cdot}89$$

$$\therefore L_1 = 12{\cdot}89 \times 3{\cdot}85$$
$$= 49{\cdot}63$$
$$= 49' \ 7\tfrac{1}{2}''$$

By Rule 17, $L_2 = m(S - G) - \dfrac{S + G}{4m}$

In this case m is the average of the angles 9 and $7\frac{3}{4}$, *i.e.*,

$$m = \frac{2 \times 9 \times 7\frac{3}{4}}{9 + 7\frac{3}{4}} = 8{\cdot}33$$

$$\therefore L_2 = 8{\cdot}33 \times 1{\cdot}75 - \frac{11{\cdot}17}{4 \times 8{\cdot}33}$$
$$= 14{\cdot}58 - {\cdot}34$$
$$= 14{\cdot}24$$
$$= 14' \ 2\tfrac{7}{8}''$$

By Rule 6 $L_3 = mG - \dfrac{G}{4m}$, m being the average of the two angles $7\frac{3}{4}$ and $5\frac{3}{4}$, *i.e.*,

$$m = \frac{2 \times 7\frac{3}{4} \times 5\frac{3}{4}}{7\frac{3}{4} + 5\frac{3}{4}} = 6{\cdot}60$$

$$\therefore L_3 = 6{\cdot}6 \times 4{\cdot}71 - \frac{4{\cdot}71}{4 \times 6{\cdot}6}$$
$$= 31{\cdot}09 - {\cdot}18$$
$$= 30{\cdot}91$$
$$= 30' \ 10\tfrac{7}{8}''.$$

By Rule 6, $L_4 = mG - \dfrac{G}{4m}$

In this case m is the average of the angles $5\frac{3}{4}$ and 5, *i.e.*,

$$m = \frac{2 \times 5\frac{3}{4} \times 5}{5\frac{3}{4} + 5} = 5{\cdot}35$$

$$\therefore L_4 = 5{\cdot}35 \times 4{\cdot}71 - \frac{4{\cdot}71}{4 \times 5{\cdot}35}$$
$$= 25{\cdot}20 - {\cdot}22$$
$$= 24{\cdot}98$$
$$= 24' \ 11\tfrac{3}{4}''.$$

The lead of the switches marked 'Y' in Fig. 149 can be obtained as shewn on p. 241, *i.e.*,

$$Y = \frac{S + G}{2 \times N_1}$$
$$= \frac{11 \cdot 17}{2 \times 9}$$
$$= \cdot 62$$
$$= 7\tfrac{3}{8}''.$$

The lead of the diamonds marked 'X' in Fig. 149 can be obtained as shewn on p. 240, *i.e.*,

$$X = \frac{G}{2N} = \frac{4 \cdot 71}{2 \times 5 \cdot 75}$$
$$= \cdot 41$$
$$= 4\tfrac{7}{8}''.$$

The full leads from tip of switches to blunt noses of the various crossings can now be obtained as under :—

1. Tip of Switch to Crossing N_1.

	L_1 =	49′ $7\frac{1}{2}''$
Switch length of 'C' type switches	=	27′ 5″
Intersection point to blunt nose $= 9 \times \frac{3}{4}''$	=	$6\frac{3}{4}''$
		77′ $7\frac{1}{4}''$

2. Tip of switch to crossing N_3.

	L_1 =	49′ $7\frac{1}{2}''$
	L_2 =	14′ $2\frac{7}{8}''$
Switch length, 'C' switches	=	27′ 5″
		91′ $3\frac{3}{8}''$
Deduct the distance from intersection point to blunt nose $= 7\frac{3}{4}'' \times \frac{3}{4}''$ =		$5\frac{13}{16}''$
		90′ $9\frac{9}{16}''$

3. Tip of switch to crossing N_4.

	L_1 =	49′ $7\frac{1}{2}''$
	L_2 =	14′ $2\frac{7}{8}''$
	L_3 =	30′ $10\frac{7}{8}''$
Switch length, 'C' switches	=	27′ 5″
		122′ $2\frac{1}{4}''$

4. Tip of switch to crossing N_5.
This length exceeds the previous by the amount 'X', and therefore, $= 122' \ 2\frac{1}{4}'' + 4\frac{7}{8}'' = 122' \ 7\frac{1}{8}''$

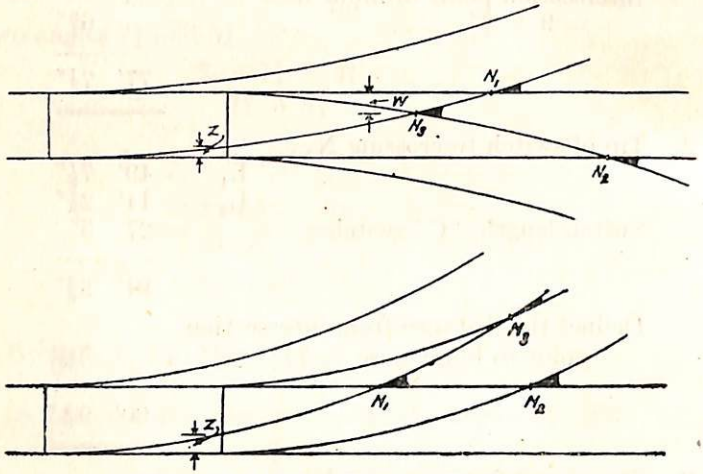
5. Tip of switch to crossing N_6.

Distance to crossing N_5 as above	$= 122' \ 7\frac{1}{8}''$
L_4	$= 24' \ 11\frac{3}{4}''$
Intersection Point to Blunt Nose $= 5 \times \frac{3}{4}''$	$= 3\frac{3}{4}''$
	$147' \ 10\frac{5}{8}''$

DOUBLE OR TANDEM TURNOUTS.

The arrangement of two turnouts as shewn in Fig. 150 and 151, where the switches of one turnout come in the lead of the other are known as 'double' or tandem turnouts.

They are very useful in confined spaces as the arrangement saves a considerable amount of space, but an additional crossing is required as shewn in the Figures.



FIGS. 150 & 151. TANDEM TURNOUTS.

Fig. 150 shews the arrangement where the turnouts diverge from the main in opposite directions, in which case the third crossing lies in the four foot of the main. Fig. 151 shews the arrangement where the two turnouts diverge in the same direction from the main, and here the third crossing lies outside the four foot of the main.

The questions of the checking of the third crossing, distance apart of switches, and spacing of timbers, make it desirable when designing tandem turnouts, to draw the layout to a large scale, and hence obtain the necessary leads and angles of crossings.

The following conditions should be observed in design :—

1. The middle set of switches should be further from the first set than the switch heel length of the first set.
2. The distance marked ' Z ' in Figs. 150 and 151 should be sufficient to allow the full opening of the middle set of switches.
3. The distance from the tip of the middle switches to the third crossing N_3 in Fig. 150 should be more than the switch heel length of the middle switches.
4. The distance marked ' W ' in Fig. 150 should be at least 1′ 2″.
5. Care must be taken to see that the crossings marked N_2 and N_3 in Fig. 151 are in such a position that they can both be properly checked.

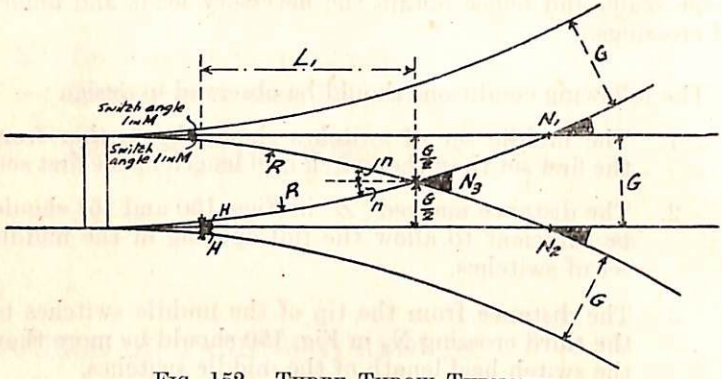
The calculation of leads and angles for tandem turnouts by the methods explained in this book are very involved unless in the type shewn in Fig. 150, the dimension ' W ' is known. and the type shewn in Fig. 151 crossings N_2 and N_3 are opposite to one another. The calculation of leads and angles can be done by trigonometry but a description of this method is beyond the scope of this book. As it is usual to draw tandem layouts to a large scale in order to ensure satisfactory chair spacing and checking, such drawing is a convenient method of design provided a large enough scale is used to enable accurate drawing to be done, 4 feet to 1 inch being a suitable scale.

THREE THROW TURNOUTS.

These are special cases of Tandem Turnouts in which the switches of the two turnouts come together. They should only be used in siding work when the space is so restricted that no other arrangement is possible. The objection to them is that it is not possible to maintain gauge at the tip of the second switch, *i.e.* when the switches are set for the middle road. There are two types as described below.

Type 1.

In this type the turnouts diverge from opposite sides of the straight track as shewn in Fig. 152.



FIG, 152. THREE THROW TURNOUTS.

In this Figure the turnout crossings N_1 and N_2 are placed opposite to each other, and, consequently, they will be of the same angle, and the radii of the two turnout curves (assuming the middle road to be straight) will be equal. The calculations are then straightforward. A line bisecting the gauge of the middle road will pass through the middle crossing N_3 dividing it into two angles each 1 in n.

The lead and radius for the turnouts of crossings N_1 and N_2 can be taken from tables or obtained as previously described.

The value of ' n ' can be obtained from Rule 33 by substituting $\frac{G}{2} - H$ ' for ' G — H ', and the angle of N_3 is then equal to $\frac{n}{2}$.

The Lead L_1 can be obtained from Rule 11a by substituting $\frac{G}{2} - H$ ' for ' G — H '.

$$i.e.\ L_1 = m\left(\frac{G}{2} - H\right)$$

m being the average of the switch angle M and the angle n.

Type 2.

In this type both turnouts branch off on the same side of the straight track. The switches to turnout 1 should have half the usual switch angle and heel offset in order that the switches to turnout 2 should have the ordinary switch angle, as shewn in the enlarged detail in Fig. 153.

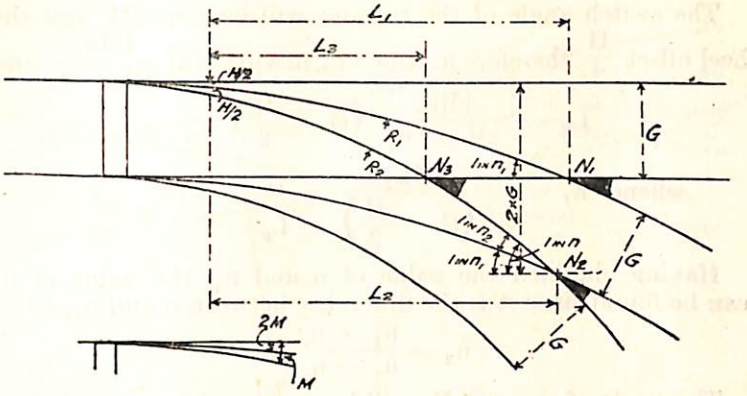


FIG. 153. THREE THROW TURNOUTS.

The switches for three throws, either type 1 or type 2, are specially made, and the angle M for straight type, or the equivalent angle M for curved type must be obtained before the leads and radii can be calculated.

As the radius of turnout 2 is sharper than that of turnout 1, it is advisable to decide on the angle of crossing N_3, and type of switch for this crossing. As explained for tandem turnouts if it is arranged for crossings N_1 and N_2 to come nearly opposite to each other, as shewn in Fig. 153, so that the distance from the fine point of crossing N_2 to the further gauge line of the straight track is 2G, it is possible to calculate the angle of crossing N_1, and the various leads and radii, by the methods of the last Chapter.

Assuming that the turnout radius R_2 to crossing N_3 has been calculated or taken from tables, the value of the angle 1 in n can be obtained from Rule 33 by substituting 'R_2' for 'R' and '2G — H' for 'G', then

$$n = \sqrt{\frac{R_2 M^2}{R_2 + 2M^2 (2G - H)}}$$

L_2 can now be obtained by use of Rule 11 by substituting therein '2G — H' for 'G — H', *i.e.*

$$L_2 = m(2G - H) - \frac{2G - H}{4m}$$

where m is the average of M and n.

Drawing a line parallel to the straight track drawn through crossing N_2, the inner rail of turnout 1 from the heel to crossing N_2 can be treated as the outer rail of a turnout over a gauge G, and the angle it makes with the line parallel to the straight track drawn through N_2 is 1 in n_1.

The switch angle of the turnout will be 1 in 2M, and the heel offset $\frac{H}{2}$, therefore in Rule 11a, m will equal $\frac{4Mn_1}{2M + n_1}$ and

$$L_2 = \frac{4Mn_1}{2M + n_1}\left(G - \frac{H}{2}\right)$$

$$\text{whence } n_1 = \frac{2ML_2}{4m\left(G - \frac{H}{2}\right) - L_2}$$

Having obtained the value of n and n_1, the value of n_2 can be found since it is the difference between n and n_1, *i.e.*

$$n_2 = \frac{n_1 \times n}{n_1 - n}.$$

The angle of crossing N_1 will be equal to 1 in n_1, and since the crossings N_1 and N_2 are equivalent to a diamond crossing over one rail of the straight track and the parallel line through N_2, the lead L_1 will exceed the lead L_2 by the amount $\frac{G}{2n_1}$ (*see* p. 240).

The Radius R_1 can be obtained from Rule 21.

As explained for tandem turnouts it is advisable to draw three throw turnouts to a large scale in order that satisfactory chair spacing and checking of crossings can be arranged.

SINGLE AND DOUBLE SLIPS.

These are standard arrangements by which connections can be made between track 1 and track 2, as shewn in Fig. 154. A single slip gives one connection between the two tracks, and a double slip gives connections in both directions.

As slip roads are a standard arrangement, they are generally supplied as one unit ready for laying in the track, but the principles of Chapter IX can be utilised to give the necessary dimensions, and as it is occasionally impracticable to use the standard arrangements, the method by which the requisite dimensions can be calculated is explained in the following pages.

Referring to Fig. 154 the leads marked L and L_1 and L_2 can be obtained as explained previously, *i.e.*

$$L = NG - \frac{G}{4N} \qquad \text{(by Rule 15).}$$

$$L_1 = NG + \frac{G}{4N} \qquad \text{(by Rule 16).}$$

$$\text{and } L_2 = 2N\left(G + \frac{G}{8N^2}\right) \qquad \text{(from Rule 44).}$$

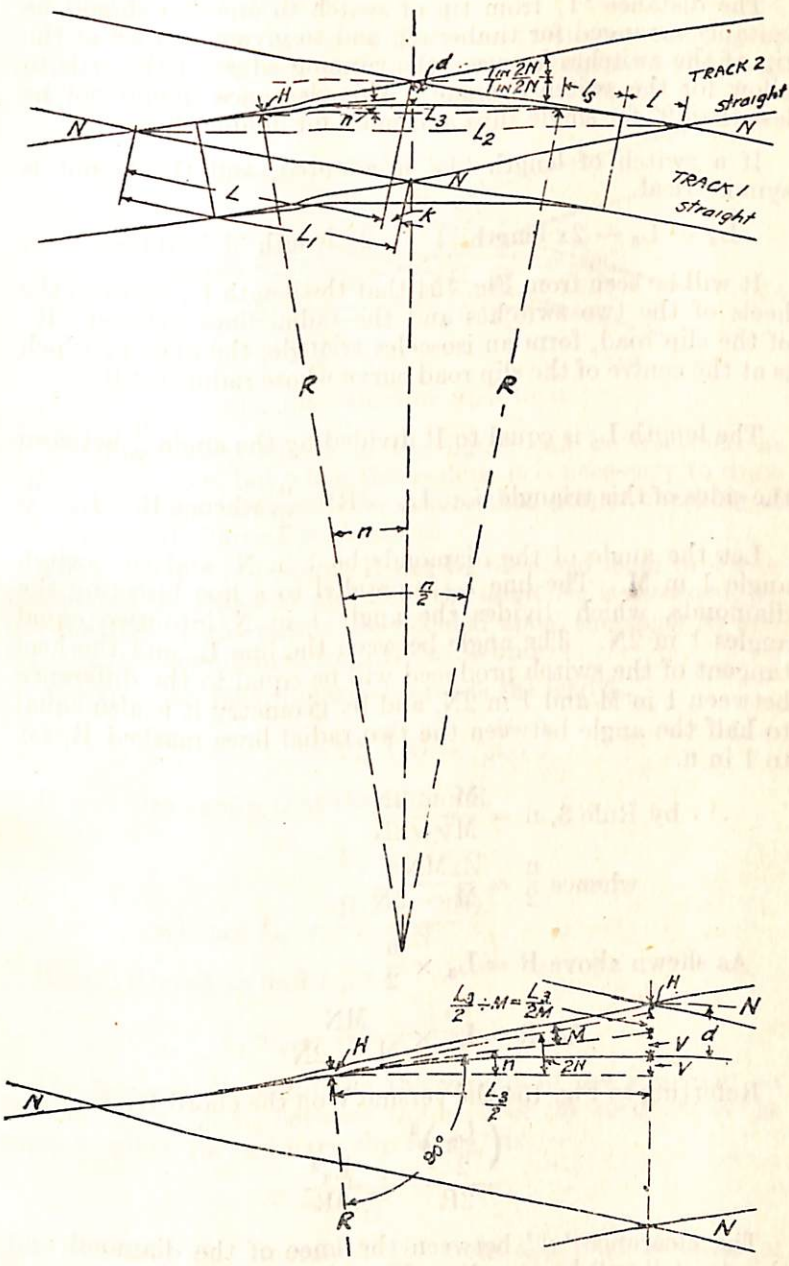


FIG. 154. SLIP ROADS.

The distance 'l' from tip of switch to crossing should be suitably arranged for timbering, and to give clearance at the tip of the switches between the running edges of the rails to allow for the switch opening. This clearance should not be less than 9″ for single slips and more for double slips.

If a switch of length 'l_s' is adopted, and the layout is symmetrical

$$L_3 = L_2 - 2x \text{ length } 'l' - 2x \text{ length } 'l_s' \text{ (approx.)}$$

It will be seen from Fig. 154 that the length L_3 between the heels of the two switches and the radial lines marked 'R' of the slip road, form an isosceles triangle, the apex of which is at the centre of the slip road curve whose radius is 'R'.

The length L_3 is equal to R divided by the angle $\frac{n}{2}$ between the sides of this triangle, *i.e.*, $L_3 = R \div \frac{n}{2}$, whence $R = L_3 \times \frac{n}{2}$.

Let the angle of the diamonds be 1 in N, and the switch angle 1 in M. The line L_3 is parallel to a line bisecting the diamonds, which divides the angle 1 in N into two equal angles 1 in 2N. The angle between the line L_3 and the heel tangent of the switch produced will be equal to the difference between 1 in M and 1 in 2N, and by geometry it is also equal to half the angle between the two radial lines marked R, *i.e.* to 1 in n.

$$\therefore \text{ by Rule 3, } n = \frac{M \times 2N}{M - 2N}$$

$$\text{whence } \frac{n}{2} = \frac{MN}{M - 2N}$$

$$\text{As shewn above } R = L_3 \times \frac{n}{2}$$

$$\textit{i.e. } R = L_3 \times \frac{MN}{M - 2N}$$

Referring to Fig. 154 the versine V on the chord $L_3 =$

$$\frac{\left(\frac{L_3}{2}\right)^2}{2R} = \frac{L_3^2}{8R}$$

The clearance 'd' between the knee of the diamond and the slip rail will be seen from Fig. 154 to be equal to

$$\frac{L_3}{2M} + H + V.$$

OUTSIDE SLIP ROADS.

In certain cases, owing to the main tracks intersecting at a sharp angle it is necessary to use the arrangement shown in Fig. 154 which is known as an ' Outside Slip Road '.

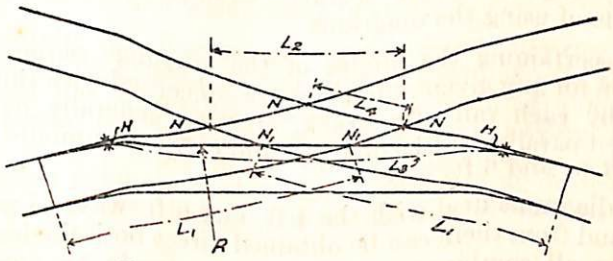


FIG. 155 OUTSIDE SLIP ROAD.

The dimensions shown in the figure can be obtained as explained below, but when this is done it is necessary to draw the design to a large scale to ensure that proper checking of crossings and chairing is obtained.

The leads L_1 and radius R can be obtained from tables or calculated by Rules 11 and 21 if the angle N_1 is assumed, or, alternatively if the radius R is decided upon, the angle N_1 and lead L_1 can be obtained from Rules 33 and 11.

As explained for ordinary slip roads the lead L_2

$$= 2N\left(G + \frac{G}{8N^2}\right)$$

It was also shewn that the radius R

$$= L_3 \frac{MN}{M - 2N}$$

$$\text{whence } L_3 = \frac{R(M - 2N)}{MN}$$

Rule 5 is used to find L_4, *i.e.*

$$L_4 = NG + \frac{G}{4N}$$

The formula for obtaining the versine of the slip road on the chord length L_3 between the heels of the turnouts is the same as given for ordinary slip roads, viz. :—

$$V = \frac{L_3^2}{8R}$$

and similarly the clearance ' d ' from slip road to knee of diamond

$$= \frac{L_3}{2M} + H + V$$

DIAGRAMS FOR OBTAINING LEADS AND RADII.

The design of layouts is simplified by the use of the diagrams included at the end of the Chapter, a description of which follows, together with worked examples illustrating the methods of using the diagrams.

In ascertaining the angles of the crossings required in a junction for any given radius, we are concerned with the angles made by each rail of a track, crossing generally over two standard parallel widths of 4′ 8½″ and 6′ 5½″, commonly known as the 4 ft. and 6 ft. ways.

The diagrams deal with the 4 ft. and 6 ft. ways as separate units, and from them can be obtained direct both the leads and radii for all combinations of crossings, made by any track crossing the 4 ft. and 6 ft. ways, within the practical limits for ordinary railway work.

No diagram has been included dealing with the lead from the switches to the first crossing, as a table of leads and radii is issued by each railway, covering the standard type of switches in use on their system. These tables can therefore be used in conjunction with the diagrams in dealing with the solution of junctions or through roads, etc.—*See* Table No. 5, p. 58, giving the standard leads of the Main Line Railways and London Passenger Transport Board Railways.

The diagrams deal with turnouts from a straight main line. Where, however, both tracks are curved, it is necessary to reduce the problem to that of an equivalent junction off the straight. Diagram 10 may be used to obtain this information.

For other than standard 6′ 5½″ spacing between tracks diagrams 11 and 12 have been prepared, these giving the increase in Lead and Radii respectively per foot of increase over the 6′ 5½″ standard spacing for any combination of crossings.

Diagrams 1 to 4 are for obtaining the *leads*, between intersection points for combinations of angles ranging between 1 in 3 and 1 in 20, for the track crossing the 4′ 8½″ way.

Diagrams 5 and 6 are for obtaining the *leads*, between intersection points for combinations of angles between 1 in 4 and 1 in 20, for the track crossing the 6′ 5½″ way.

On the "*lead*" diagrams, the vertical divisions are for reading off the length of "*lead*" and are figured in feet at the top and bottom of the diagrams, each foot being sub-divided into 1/12ths, so that the length can be read directly to the nearest inch, or judged to the nearest ½″. One angle of the

combination is given at either side, and can be read to the nearest 1/10th of a unit, the quarter units also being shewn; while the other angle of the combination is given on the curved line or graph, and advance in quarter units to 1 in 5, in half units to 1 in 11, and whole units beyond.

In reading the diagram the angle of one crossing in the combination is located at the side of the diagram, and the horizontal line indicating this angle is followed along until it intersects the curve representing, and having figured against it, the other angle of the combination. At this intersection point the vertical line is followed up or down and the length of the 'lead' read at the top or bottom of the diagram.

On the diagram giving the "leads" across the 4 ft. way it will be seen that two leads are given, one by a curved full line and the other by a curved dotted line. The full line gives the square lead "L" between the crossings, and the dotted line the distance "L_1" between the intersection points of the two crossings of the combination. This latter distance is a more useful dimension to use in some cases than the square lead "L".

Diagrams 7 and 8 are for obtaining the *radii* for similar combinations of crossings within the limits mentioned, where the track crosses the 4′ 8½″ and 6′ 5½″ way respectively.

The diagrams giving the "Radii" are read in a similar manner to the "Lead" diagrams. The radii are shewn in chains at the top and bottom of the diagrams. Each vertical division represents ½ chain up to 20 chains. Beyond 20 chains and up to 100 chains each division equals 1 chain. Beyond 100 chains each division represents 5 chains on the diagram for curves across the 4 ft. way, and 2 chains on the diagram for curves across the 6 ft. way. The radius is, of course, that of the rail on which the crossings lie, but as it is given in chains it can be taken as indicating the radius of either rail, the difference being only 5 ft. and therefore immaterial in obtaining the necessary combination of crossings required. The angles of the crossings are shewn in a similar manner to those on the 'lead' diagrams, excepting that the horizontal divisions are spaced in 1/10ths of a unit throughout on diagram 8, and on diagram 7 from 1 in 3 to 1 in 18, and in 1/5ths of a unit beyond 1 in 18 to 1 in 20. Quarter and half units are also marked on the scale on each side of both diagrams.

Diagram 9 gives the *square lead* "X" between the diamond crossings; also the square lead "Y" between the two front crossings of a junction, in order to obtain the true 6′ 5½″ way

between the two tracks of the junction ; and also the distance " Z " from intersection point to the $\frac{3}{4}$" working nose of ordinary crossings.

Diagram 10 gives the equivalent Radius from a straight main line, where both main and turnout are curved. In preparing this diagram it has been assumed that the main line curve is in all cases of a larger radius than the turnout curve and this is so in the majority of cases. Where, however, the turnout curve is of a larger radius than the main line the former must be considered as the ' main line ' in using the diagram ; that is, the larger radius of the junction in every case is represented by the diagonal lines marked on the diagram " Radii of Main Line."

Alternatively the rules given in Chapter IX, p. 283 can be used if more accurate results are required than can be obtained from the diagram.

Diagrams 11 and 12 as previously stated give the increase in lead and radii respectively, per foot of increase over the 6′ 5½″ standard spacing for any combination of crossings. In obtaining the radius for a given combination of crossings the amount of increase read from diagram No. 12 must be added to that read from diagram No. 8 for every foot of increase over the 6′ 5½″ way. For example, the radius across a 6′ 5½″ way for crossings 1 in 9 to 1 in 7½ is 10 chains (see diagram 8) ; the increase per foot read from diagram No. 12 for crossings 1 in 9 to 1 in 7½ is 5½ chains, obtained thus :—follow along the horizontal line marked 9 on diagram No. 12 until it intersects the curved line marked 7½, then follow vertically downwards to the bottom scale ; the intersection of the 9 and 7½ lines is found to be half way between 5 and 6, thus 5½ chains is the required increase. Therefore, for spacing of 6′ 11½″, i.e. 6″ increase, 2¾″ chains must be added to the radius across the 6′ 5½″ way ; for a spacing of 7′ 5½″, i.e. 1 foot increase, 5½ chains must be added ; for a spacing of 7′ 11½″, i.e. 1′ 6″ increase, 8¼ chains must be added and so on. See tabulated results below :—

Crossings 1 in 9 to 1 in 7½ across	6′	5½″	Radius	= 10	Chains. (see dia. 8).		
,, ,, ,,	,,	6′ 11½″	,,	= 10 + 2¾	= 12¾	chains.	
,, ,, ,,	,,	7′ 5½″	,,	= 10 + 5½	= 15½	,,	
,, ,, ,,	,,	7′ 11½″	,,	= 10 + 8¼	= 18¼	,,	
,, ,, ,,	,,	8′ 5½″	,,	= 10 + 11	= 21	,,	
,, ,, ,,	,,	9′ 5½″	,,	= 10 + 16½	= 26½	,,	
,, ,, ,,	,,	10′ 5½″	,,	= 10 + 22	= 32	,,	

The increase in lead is obtained in a similar manner, *i.e.*, the amount of increase read from Diagram No. 11 must be added to that read from diagrams Nos. 5 and 6 for every foot

of increase over the 6′ 5½″ way. Taking the same combination of crossings as previously given, viz., 1 in 9 to 1 in 7½, follow along the horizontal line marked 9 on diagram No. 11 until it intersects the diagonal line marked 1 in 7½, follow the vertical line down to the scale at the bottom of the diagram where 8′ 2″ will be found to be the increase per foot. Therefore, for every foot or part of a foot the 6′ 5½″ way is increased, 8′ 2″ or a proportional part of this amount must be added. See tabulated results below.

Crossings—

1 in 9 to 1 in 7½	across	6′ 5½″	way	Lead	=13′ 11½″ (see dia. 5).
,, ,,	,,	6′ 11½″	,,		=13′ 11½″ + 4′ 1″ =18′ 0½″
,, ,,	,,	7′ 5½″	,,		=13′ 11½″ + 8′ 2″ =22′ 1½″
,, ,,	,,	7′ 11½″	,,		=13′ 11½″ +12′ 3″ =26′ 2½″
,, ,,	,,	8′ 5½″	,,		=13′ 11½″ +16′ 4″ =30′ 3½″
,, ,,	,,	9′ 5½″	,,		=13′ 11½″ +24′ 6″ =38′ 5½″
,, ,,	,,	10′ 5½″	,,		=13′ 11½″ +32′ 8″ =46′ 7½″

Examples.

In solving any problem it is best to make a form as shewn under Examples 1, 2 and 3 (*see* Examples sheet following p. 321), putting in the various headings and entering the combinations of crossings, radii, and leads, as they are obtained from the diagrams. Taking Example 1, the problem being a junction of about 20 chains radius off a straight main line :—

The Railway Engineer's Association new Standard "E" type switch in combination with a 1 in 12½ crossing gives a radius of 20¾ chains and lead to intersection point of 115′ 6⅝″. Accepting the 12½ as the first crossing, and entering it together with the length of lead and radius, in their respective columns, proceed to find the next crossing, viz.—that marked 2 on Diagram 9, which will give the required radius in combination with the 1 in 12½. Turning to Diagram 8, giving radii across 6′ 5½″ way, find the horizontal line, indicating crossing angle of 1 in 12½ by reading the scale on the right-hand side of the diagram, and following it across until it meets the vertical line marked 20 chains (the scale of which is marked at the top and bottom). At this point the curved line marked 10½ is also met, thus indicating that a 1 in 12½ in combination with a 1 in 10½ will give a radius of 20 chains across the 6′ 5½″ way. The 1 in 10½ is therefore the crossing required.

Entering the 1 in 10½ crossing and the radius on the list and turning to Diagram 7 giving radii across 4′ 8½″ way, follow the horizontal line indicating crossing angle of 1 in 10½ until it meets the vertical line marked 20 chains. Two divisions to the left of this point the curved line marked 1 in 8 is met. This is therefore the required angle of the

diamonds. Each division between 20 and 100 represents one chain, therefore a 1 in $10\frac{1}{2}$ in combination with a 1 in 8 across the 4′ $8\frac{1}{2}$″ way gives a radius of 22 chains. On the same diagram, following the horizontal line marked 8 across in the same manner as before, at 20 plus three divisions, i.e., 23 chains, a point is found which is half way between the two curved lines representing 1 in $6\frac{1}{2}$ and 1 in 7. The angle of crossing required is therefore 1 in $6\frac{3}{4}$.

The required crossings for the junction having been obtained, proceed to find the leads for the various combinations. The first lead required is the distance from the 1 in $12\frac{1}{2}$ to the 1 in $10\frac{1}{2}$ across the 6 ft. way. Turning to Diagram 6, follow the horizontal line representing a 1 in $12\frac{1}{2}$ crossing (see scale of units on side of Diagram) until it meets the curved line marked $10\frac{1}{2}$. This intersection is at 19′ $8\frac{1}{2}$″ on the vertical scale, which is marked in feet at the top and bottom. On Diagram 2, in the same manner, find the lead

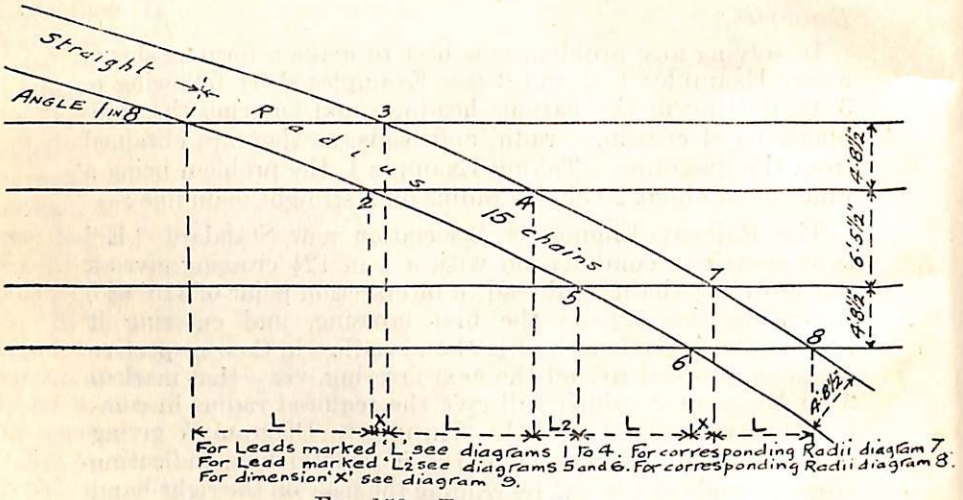


FIG. 156. THROUGH ROAD.

" L " for the combination of 1 in $10\frac{1}{2}$ and 1 in 8, which is found to be 42′ $7\frac{1}{2}$″, and that for the 1 in 8 to 1 in $6\frac{3}{4}$, viz.—34′ $3\frac{1}{2}$″, using the curved full line in both cases. In the latter case the horizontal line representing 1 in $6\frac{3}{4}$ is taken in conjunction with the curved line representing 1 in 8, as no curved line is shewn for the 1 in $6\frac{3}{4}$. Having now obtained the required leads to intersection points, those between the actual noses can be found by adding or deducting the dimension " Z " given on Diagram 9. The amounts to be added or deducted and the resultant leads between the actual noses of the crossings are shewn in Example 1.

Example 2 is for a through road of about 15 chains radius, crossing a double track (*see* Fig. 156). The angle of crossing "1" being a 1 in 8, find the angles and leads of the other crossings required :—

Proceed as previously described in Example 1, and obtain crossing No. 2 by turning to sheet 7 for radii across 4′ 8½″ way, following the horizontal line marked 8 on the right-hand side, until it meets the vertical line marked 15, at top and bottom, this point is about half-way between the two curved lines marked 1 in 6 and 1 in 6½. If a 1 in 6¼ is taken it will lie half way between the two above mentioned lines, and will intersect the horizontal line marked 8 at the vertical line, one division to the right of that marked 15, the radius therefore being 14½ chains.

Proceed along the same lines to find the remaining angles, and also the leads which are all listed under Example 2.

Example 3 is for a junction from a branch line with a radius of 30 chains, out of a main line curving in the opposite direction with radius of 39 chains.

Turning to Diagram 10, as the curves are of contrary flexure, see note on diagram, the radius of turnout of junction, viz. ; 30 chains, must be read on the horizontal scale B, and the equivalent radius off a straight main line on the vertical scale A. Find 30 on Scale B, follow the vertical line upwards until it intersects the diagonal line marked 40, this being the nearest line on the diagram to the 39 chains main line radius. It will be seen that the intersection of the vertical and diagonal lines is immediately above a horizontal line which, if followed to the left to scale A, reads two divisions above the line marked 15, thus representing 17 chains which is the equivalent radius desired.

The angles and leads required will then be the same as those for a junction of 17 chains radius off a straight main line.

EXAMPLE 1.

Main Line straight. Branch line about 20 chains Radius.

COMBINATION OF CROSSINGS. Across 6′ 5½″ way.	Across 4′ 8½″ way.	Radii in Chains.	Leads "L" to intersection points.	Dimension "Z" to be added or deducted as shewn.	Leads to actual nose.
1 in 12½ and 1 in 10½	REA 'E' switches and 1 in 12½ crossing	20¾	115′ 6⅝″	add 9⅜″ for 1 in 12½	116′ 4″
		20	19′ 8½″	deduct (9⅜″ + 7⅞″)	18′ 3¼″
	1 in 10½ and 1 in 8	22	42′ 7½″	add 7⅞″ for 1 in 10½	43′ 3⅜″
	Dimension X for 1 in 8 diamonds ..	—	3½″	—	3½″
	1 in 8 and 1 in 6¾	23	34′ 3½″	add 5 1/16″ for 1 in 6¾″	34′ 8 9/16″
	Overall dimensions	—	212′ 5⅝″	—	212′ 10 11/16″

EXAMPLE 2.

(Fig. 156). Main Line straight. Through road about 15 chains Radius.

COMBINATION OF CROSSINGS. Across 6′ 5½″ way.	Across 4′ 8½″ way.	Radii in Chains.	Leads "L" to intersection points.	Dimension "Z" to be added or deducted as shewn.	Leads to actual nose.
1 in 5¼ and 1 in 5	1 in 8 and 1 in 6¼	14⅓	32′ 10½″	add 6″ for 1 in 8	33′ 4½″
	Dimension X for 1 in 6¼ diamonds ..	—	4⅓″	—	4⅓″
	1 in 6¼ and 1 in 5¼	14	26′ 7½″	add 3 15/16″ for 1 in 5¼	26′ 11 7/16″
		15	8′ 5″	deduct (3 15/16 + 3¾″)	7′ 9 5/16″
	1 in 5 and 1 in 4½	15	22′ 1″	add 3¾″ for 1 in 5	22′ 4¾″
	Dimension X for 1 in 4½ diamonds ..	—	6¼″	—	6¼″
	1 in 4½ and 1 in 4⅛	15	20′ 0″	add 3 1/16″ for 1 in 4⅛″	20′ 3 1/16″
	Overall dimensions	—	110′ 10¾″	—	111′ 7 13/16″

EXAMPLE 3.

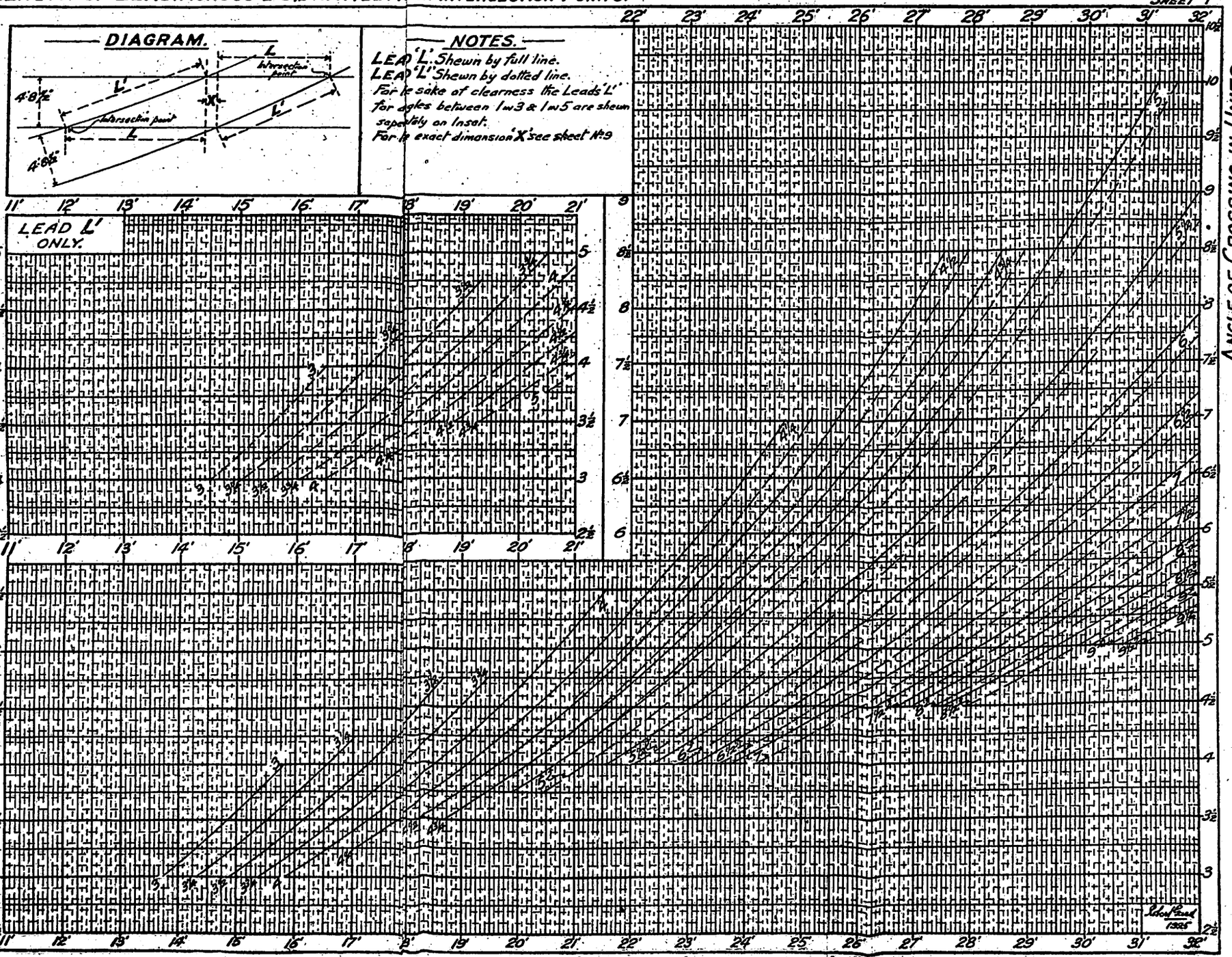
Main Line curve Radius 39 chains.
Branch line curve Radius 30 chains.
Curvature in opposite direction.
Equivalent radius off the straight 17 chains.

COMBINATION OF CROSSINGS. Across 6′ 5½″ way.	Across 4′ 8½″ way.	Radii in Chains.	Leads "L" to intersection points.	Dimension "Z" to be added or deducted as shewn.	Leads to actual nose.
1 in 11 and 1 in 9¼	REA 'D' switches and 1 in 11 crossing	17	93′ 2¾″	add 8¼″ for 1 in 11	93′ 11″
		16	17′ 4″	deduct (8¼″ + 6 15/16″)	16′ 0 13/16″
	1 in 9¼ and 1 in 7	16½	37′ 4½″	add 6 15/16″ for 1 in 9¼	37′ 11 7/16″
	Dimension X for 1 in 7 diamonds ..	—	4″	—	4″
	*1 in 7 and 1 in 5¾	15	29′ 6½″	add 4 5/16″ for 1 in 5¾″	29′ 10 13/16″
	Overall dimensions	—	177′ 9¾″	—	178′ 2 1/16″

* Or a 1 in 7 in combination with a 1 in 6 can be used giving a radius of 19½ chains and a lead of 30′ 3″

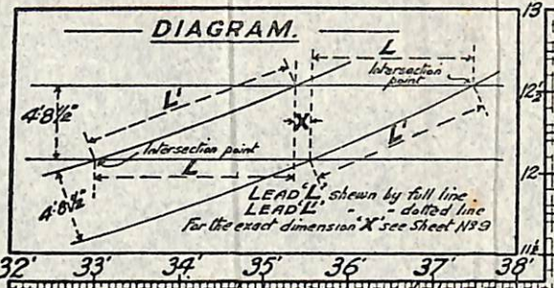
LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS.

SHEET 1



LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS.

SHEET 2



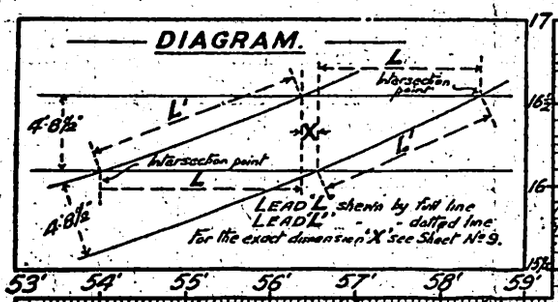
ANGLE OF CROSSING IN UNITS.

ANGLE OF CROSSING IN UNITS.

LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS

LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS.

SHEET 3

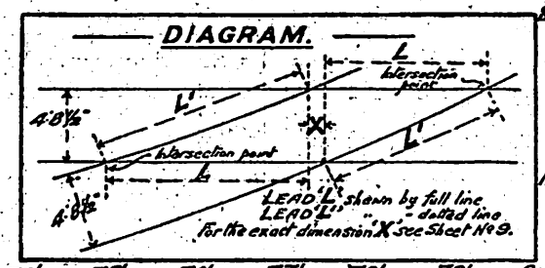


ANGLE OF CROSSING IN UNITS.

LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS.

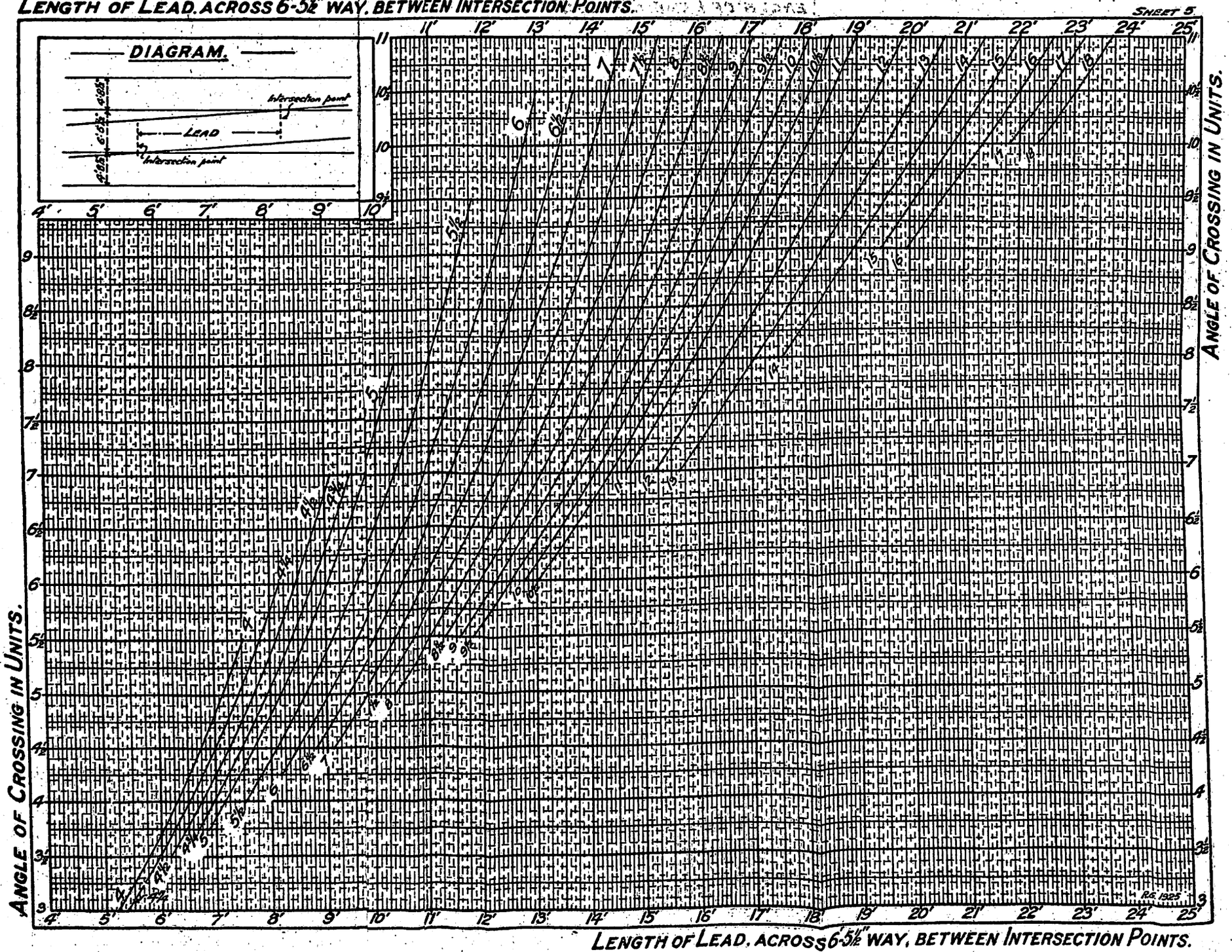
LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS.

SHEET 4



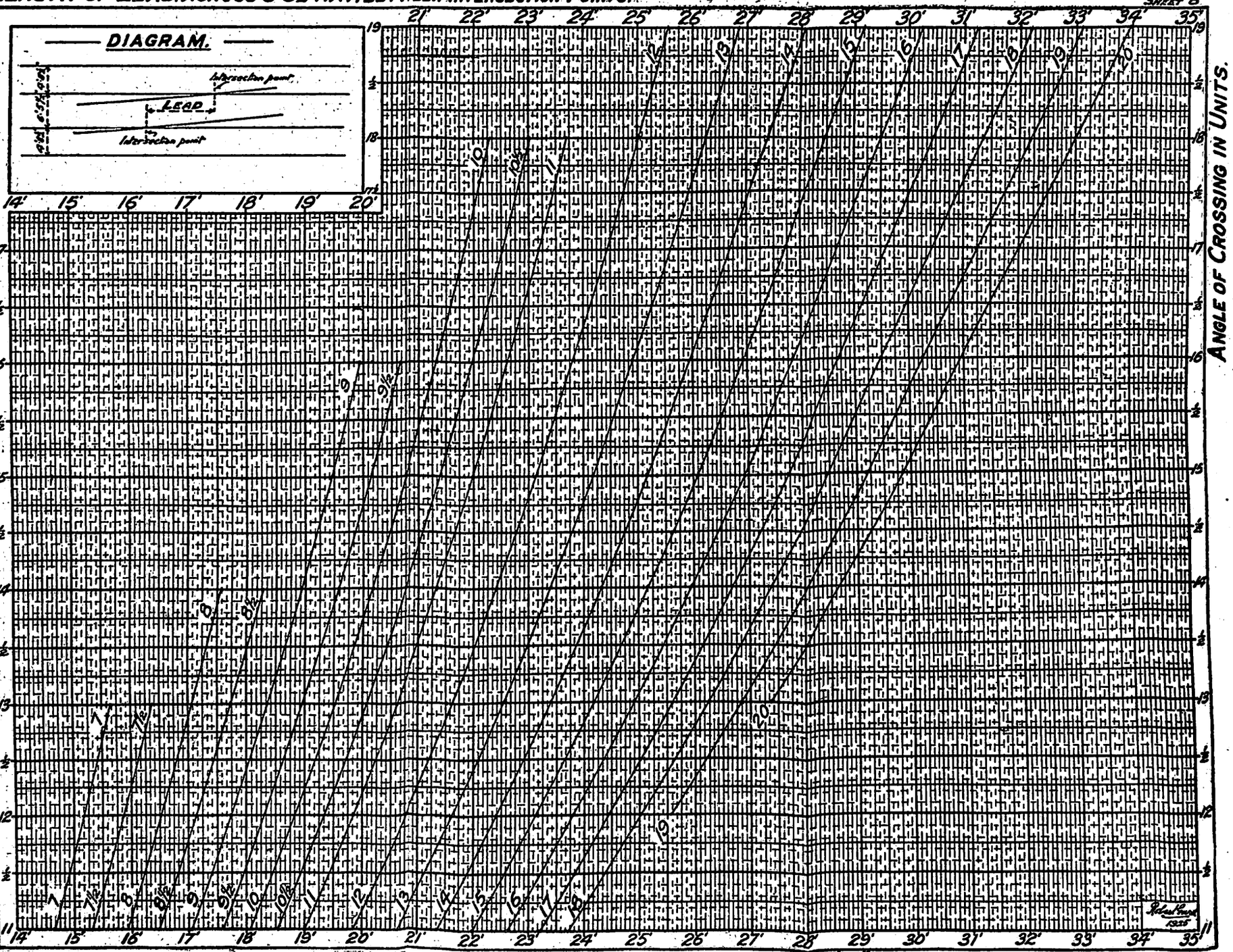
ANGLE OF CROSSING IN UNITS.

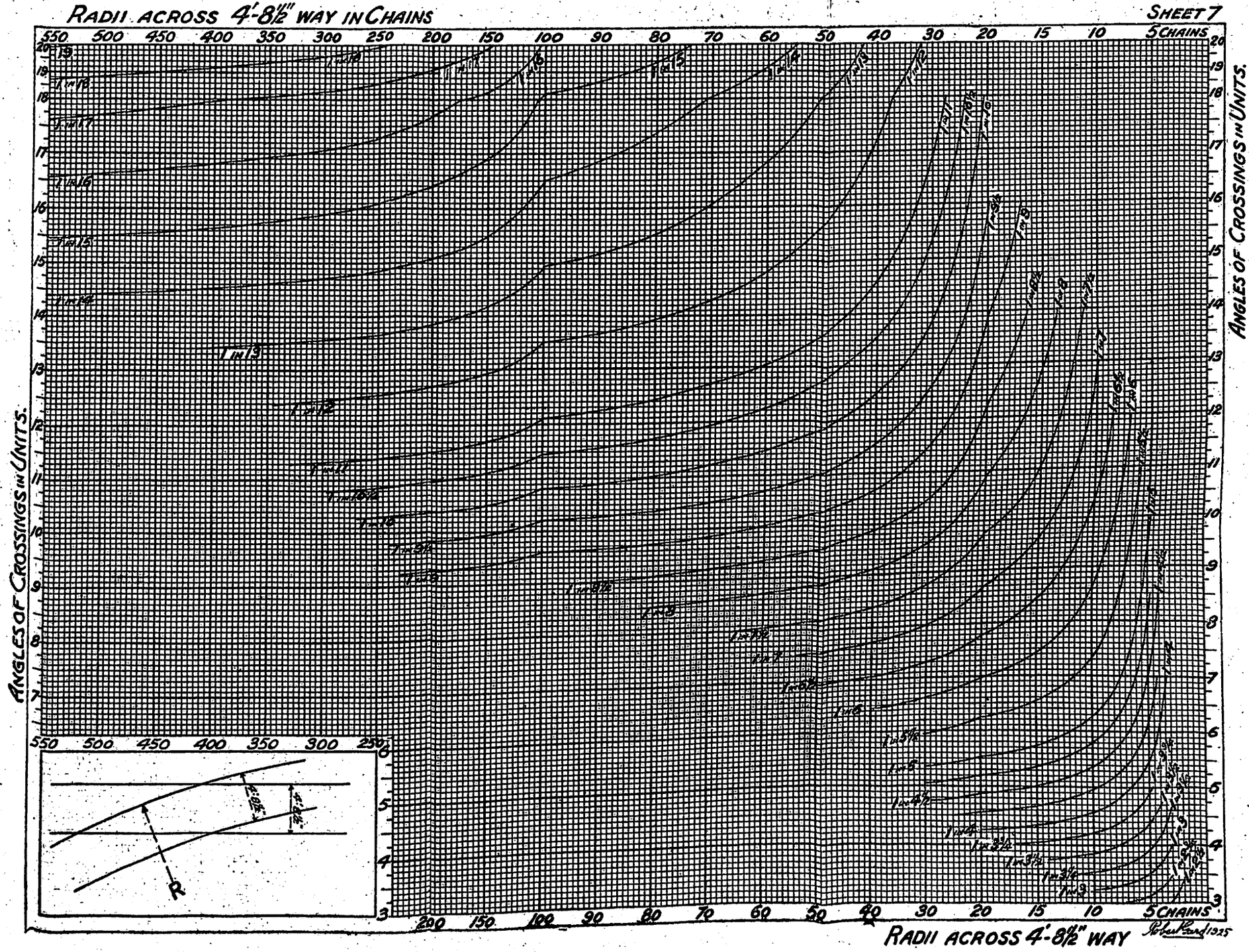
LENGTH OF LEAD. ACROSS 4'-8½" WAY. BETWEEN INTERSECTION POINTS.

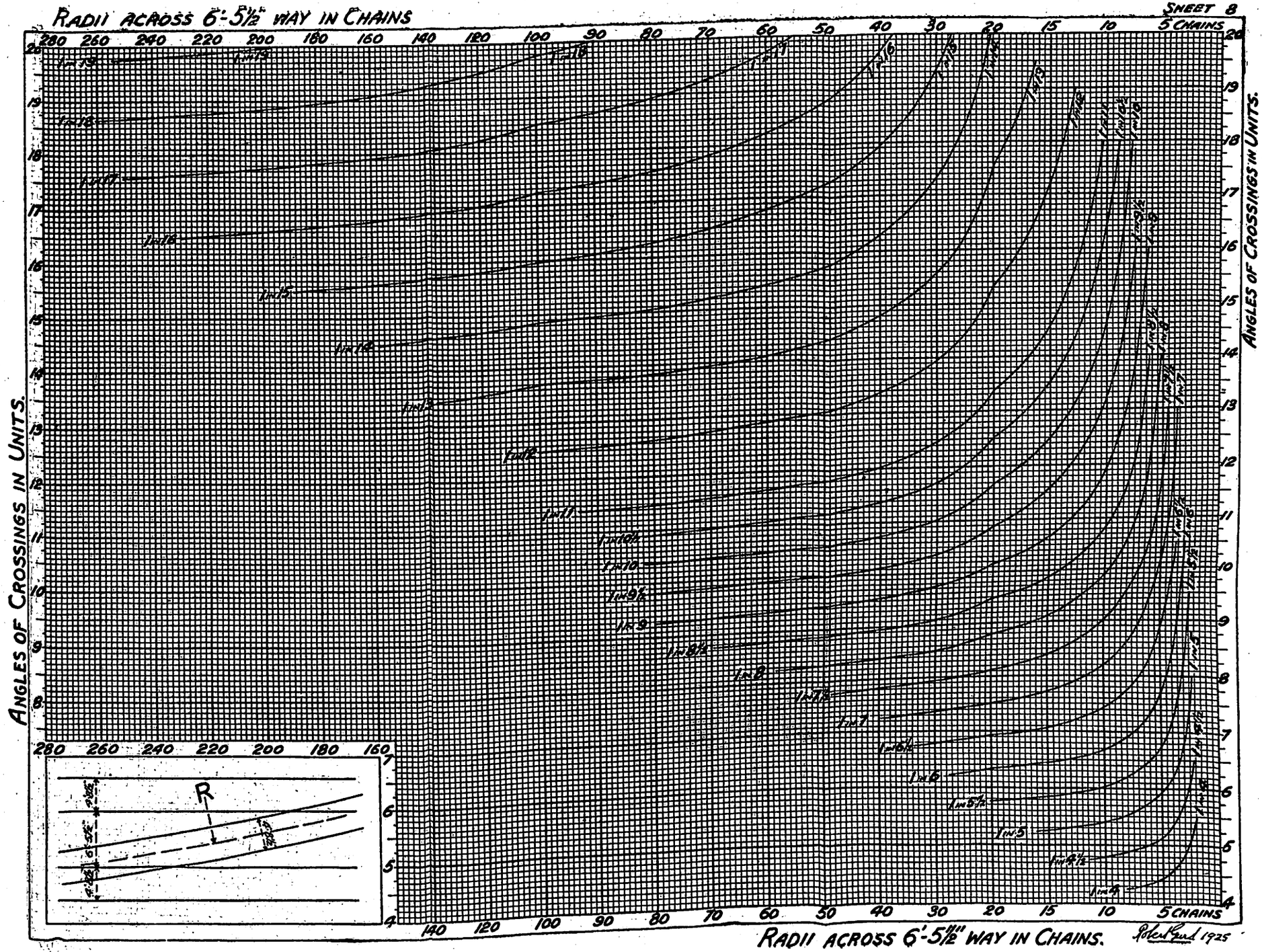

LENGTH OF LEAD. ACROSS 6'-5½" WAY. BETWEEN INTERSECTION POINTS.
SHEET 5.
DIAGRAM.
Intersection point
LEAD
Intersection point
ANGLE OF CROSSING IN UNITS.
ANGLE OF CROSSING IN UNITS.
LENGTH OF LEAD. ACROSS 6'-5½" WAY, BETWEEN INTERSECTION POINTS.
R.S. 1925

LENGTH OF LEAD. ACROSS 6'-5½" WAY. BETWEEN INTERSECTION POINTS.

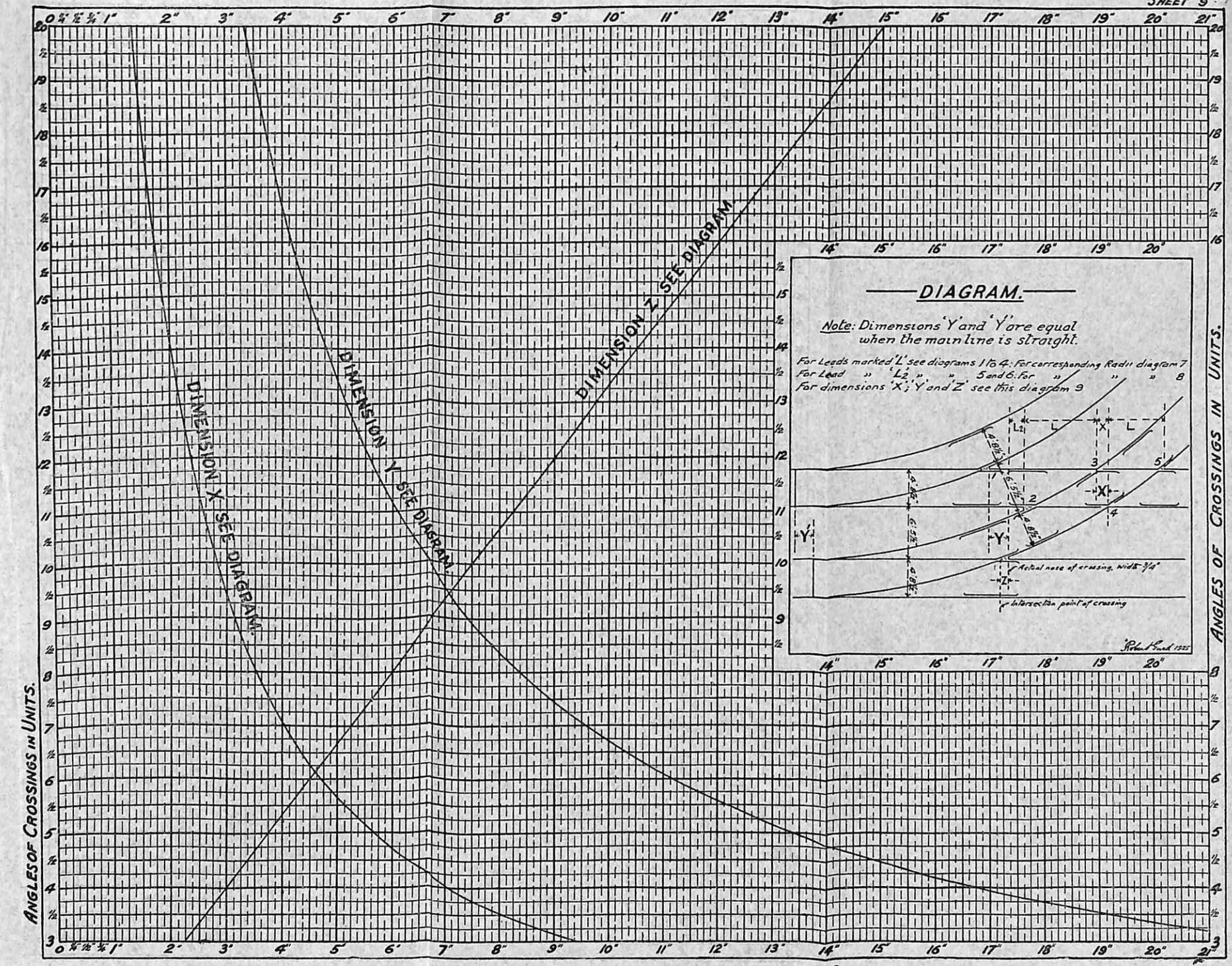
SHEET 6



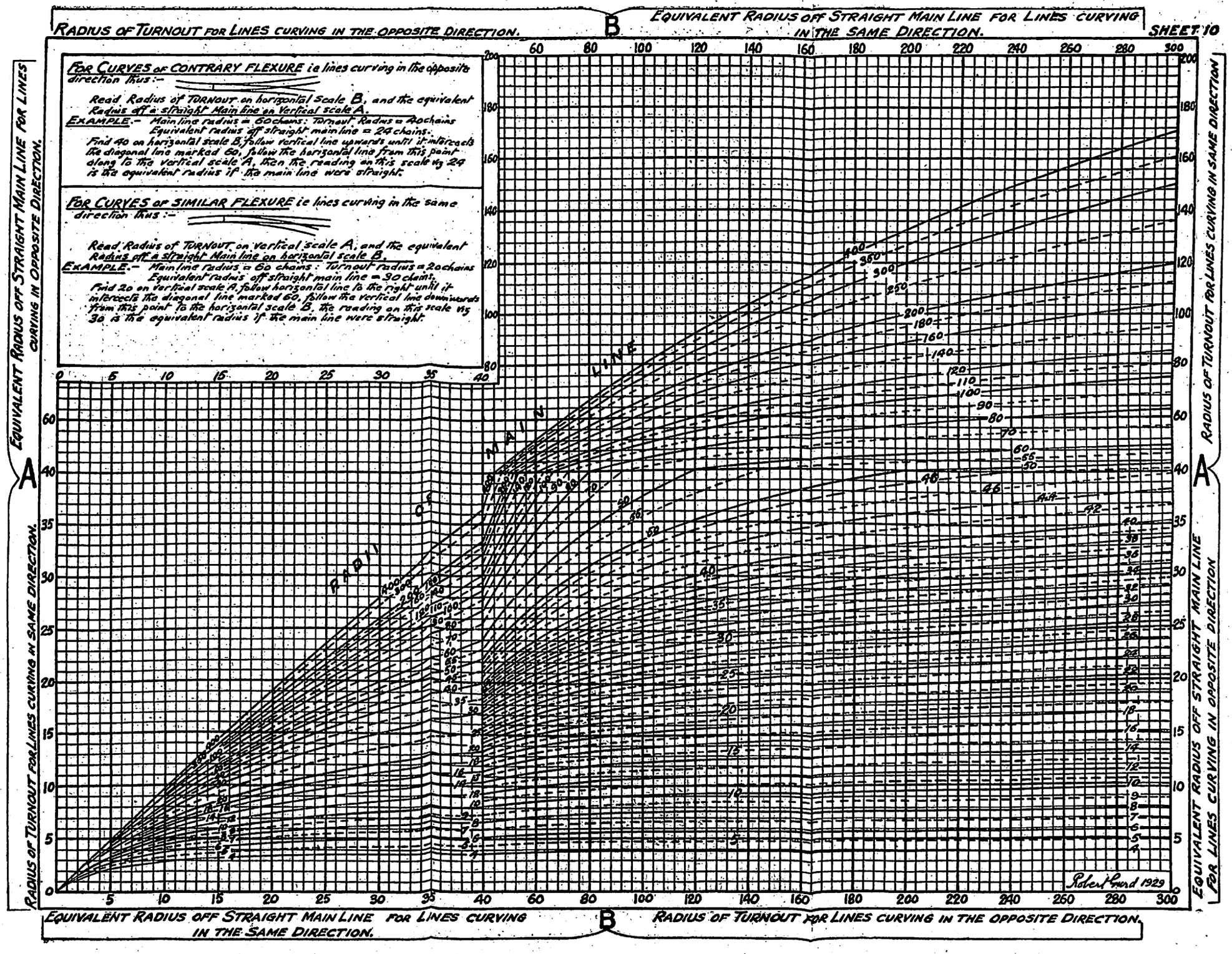

RADII ACROSS 4'-8½" WAY IN CHAINS
SHEET 7
5 CHAINS
ANGLES OF CROSSINGS IN UNITS.
1 IN 19
1 IN 18
1 IN 17
1 IN 16
1 IN 15
1 IN 14
1 IN 13
1 IN 12
1 IN 11
1 IN 10½
1 IN 10
1 IN 9½
1 IN 9
1 IN 8½
1 IN 8
1 IN 7½
1 IN 7
1 IN 6½
1 IN 6
1 IN 5½
1 IN 5
1 IN 4½
1 IN 4
1 IN 3½
1 IN 3
4'-8½"
R
RADII ACROSS 4'-8½" WAY
Robert Rand 1925


RADII ACROSS 6'-5½" WAY IN CHAINS
SHEET 8
5 CHAINS
ANGLES OF CROSSINGS IN UNITS.
ANGLES OF CROSSINGS IN UNITS.
1 in 19
1 in 18
1 in 17
1 in 16
1 in 15
1 in 14
1 in 13
1 in 12
1 in 11
1 in 10½
1 in 10
1 in 9½
1 in 9
1 in 8½
1 in 8
1 in 7½
1 in 7
1 in 6½
1 in 6
1 in 5½
1 in 5
1 in 4½
1 in 4
R
RADII ACROSS 6'-5½" WAY IN CHAINS.
Robert Reed 1925

SHEET 9

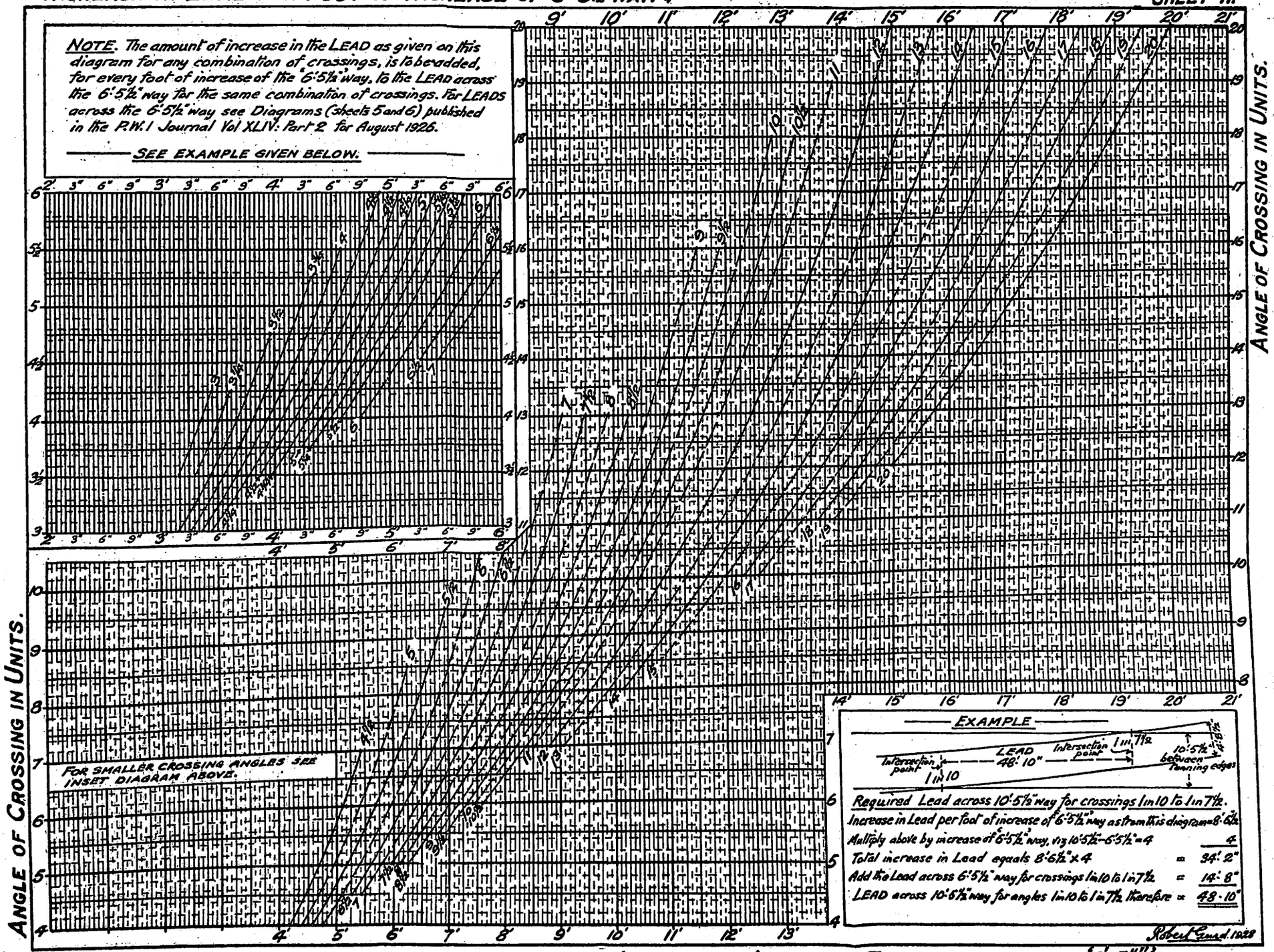

ANGLES OF CROSSINGS IN UNITS.
ANGLES OF CROSSINGS IN UNITS.
DIMENSION X SEE DIAGRAM.
DIMENSION Y SEE DIAGRAM.
DIMENSION Z SEE DIAGRAM.
DIAGRAM.
Note: Dimensions 'Y' and 'Y' are equal when the main line is straight.
For Leads marked 'L' see diagrams 1 to 4: For corresponding Radii diagram 7
For Lead " 'L2' " " 5 and 6. For " " " 8
For dimensions 'X', 'Y' and 'Z' see this diagram 9
Actual note of crossing, width 3/4"
Intersection point of crossing
Robert Sund 1925

SHEET 10


RADIUS OF TURNOUT FOR LINES CURVING IN THE OPPOSITE DIRECTION.
B
EQUIVALENT RADIUS OFF STRAIGHT MAIN LINE FOR LINES CURVING IN THE SAME DIRECTION.
EQUIVALENT RADIUS OFF STRAIGHT MAIN LINE FOR LINES CURVING IN THE SAME DIRECTION.
A
RADIUS OF TURNOUT FOR LINES CURVING IN THE OPPOSITE DIRECTION.
FOR CURVES of CONTRARY FLEXURE ie lines curving in the opposite direction thus :-
Read Radius of TURNOUT on horizontal scale B, and the equivalent Radius off a straight Main line on Vertical scale A.
EXAMPLE.- Main line radius = 60 chains: Turnout Radius = 20 chains
Equivalent radius off straight main line = 24 chains.
Find 40 on horizontal scale B, follow vertical line upwards until it intersects the diagonal line marked 60, follow the horizontal line from this point along to the vertical scale A, then the reading on this scale viz 24 is the equivalent radius if the main line were straight.
FOR CURVES of SIMILAR FLEXURE ie lines curving in the same direction thus :-
Read Radius of TURNOUT on vertical scale A, and the equivalent Radius off a straight Main line on horizontal scale B.
EXAMPLE.- Main line radius = 60 chains : Turnout radius = 20 chains
Equivalent radius off straight main line = 30 chains.
Find 20 on vertical scale A, follow horizontal line to the right until it intersects the diagonal line marked 60, follow the vertical line downwards from this point to the horizontal scale B, the reading on this scale viz 30 is the equivalent radius if the main line were straight.
MAIN LINE
OFF
Robert Ford 1929

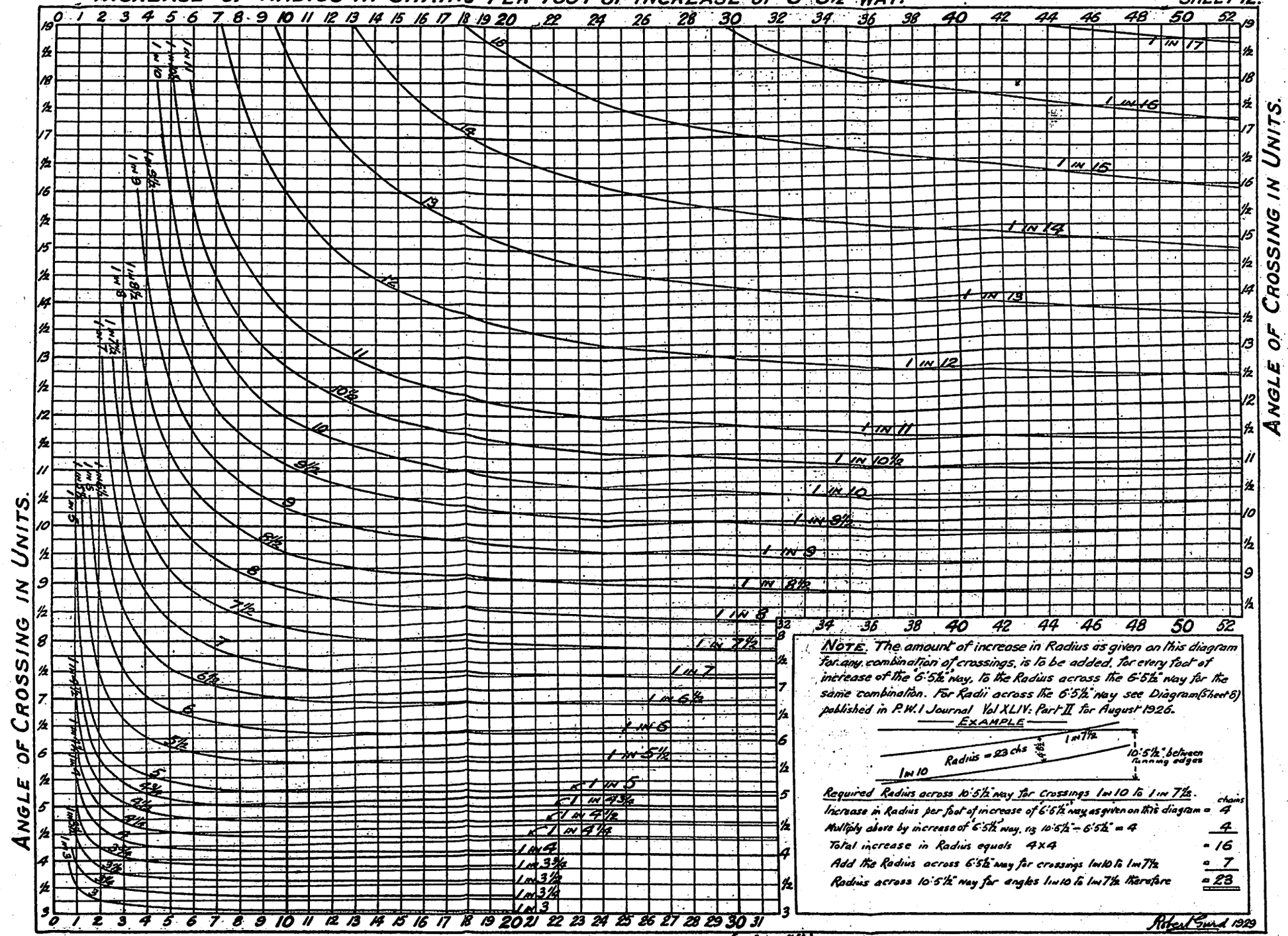
INCREASE IN LEAD PER FOOT OF INCREASE OF 6'-5½" WAY.

SHEET 11.


NOTE. The amount of increase in the LEAD as given on this diagram for any combination of crossings, is to be added, for every foot of increase of the 6'-5½" way, to the LEAD across the 6'-5½" way for the same combination of crossings. For LEADS across the 6'-5½" way see Diagrams (sheets 5 and 6) published in the P.W.I Journal Vol XLIV: Part 2 for August 1928.
SEE EXAMPLE GIVEN BELOW.
FOR SMALLER CROSSING ANGLES SEE INSET DIAGRAM ABOVE.
EXAMPLE
Intersection point
1 in 10
LEAD 48'-10"
Intersection point
1 in 7½
10'-5½" between running edges
Required Lead across 10'-5½" way for crossings 1 in 10 to 1 in 7½.
Increase in Lead per foot of increase of 6'-5½" way as from this diagram = 8'-6½
Multiply above by increase of 6'-5½" way, viz 10'-5½"-6'-5½" = 4 4
Total increase in Lead equals 8'-6½" x 4 = 34'-2"
Add the Lead across 6'-5½" way for crossings 1 in 10 to 1 in 7½ = 14'-8"
LEAD across 10'-6½" way for angles 1 in 10 to 1 in 7½ therefore = 48'-10"
Robert Gaud. 1928
ANGLE OF CROSSING IN UNITS.
INCREASE IN LEAD PER FOOT OF INCREASE OF 6'-5½".

INCREASE OF RADIUS IN CHAINS PER FOOT OF INCREASE OF 6'-5½" WAY.

SHEET 12.



NOTE. The amount of increase in Radius as given on this diagram for any combination of crossings, is to be added, for every foot of increase of the 6'-5½" way, to the Radius across the 6'-5½" way for the same combination. For Radii across the 6'-5½" way see Diagram (Sheet 6) published in P.W.I. Journal Vol XLIV: Part II for August 1926.

EXAMPLE

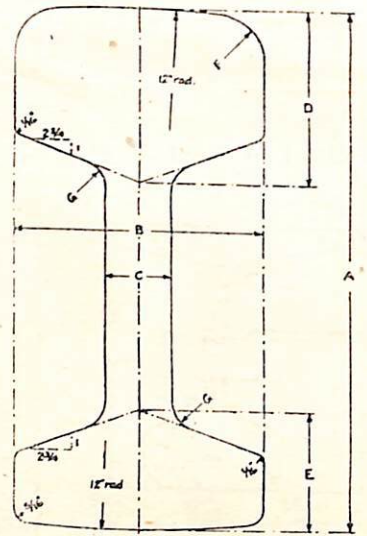
	chains
Required Radius across 10'-5½" way for Crossings 1 in 10 to 1 in 7½.	
Increase in Radius per foot of increase of 6'-5½" way as given on this diagram =	4
Multiply above by increase of 6'-5½" way, viz 10'-5½" − 6'-5½" = 4	4
Total increase in Radius equals 4×4	= 16
Add the Radius across 6'-5½" way for crossings 1 in 10 to 1 in 7½	= 7
Radius across 10'-5½" way for angles 1 in 10 to 1 in 7½ therefore	= 23

Robert Rowd 1929

INCREASE OF RADIUS IN CHAINS PER FOOT OF INCREASE OF 6'-5½" WAY.

TABLE No. 6.
BRITISH STANDARD BULL HEAD RAILWAY RAILS.
DIMENSIONS OF SECTIONS

B.S. No. and Nominal Weight Lb. Per Yard.	A	B	C	D	E	F	G
	in.	in.	in.	in.	in.	in.	in.
60	4¾	2 5/16	1 7/32	1 27/64	1 3/64	3/8	1/4
65	4⅞	2⅜	9/16	1½	1 3/32		
70	5	2 7/16	1 9/32	1 37/64	1 9/64		5/16
75	5⅛	2½	⅝	1 41/64	1 13/64		
80	5⅜	2 9/16	2 1/32	1 11/16	1 7/32		
85*	5 15/32	2 11/16	1 1/16	1¾	1¼	½	¼
85R	5 15/32	2 11/16	1 1/16	1 13/16	1 3/16		
90*	5 35/64	2¾	¾	1 25/32	1 19/64		
90R	5 35/64			1 55/64	1 7/32		
95*	5 23/32			1 29/32	1 11/32		
95R	5 23/32			1 15/16	1 5/16		
100	5 29/32			2 3/32	1 11/32		



KEY TO TABLE OF DIMENSIONS.

The dimensions figured on the key apply to all sections.

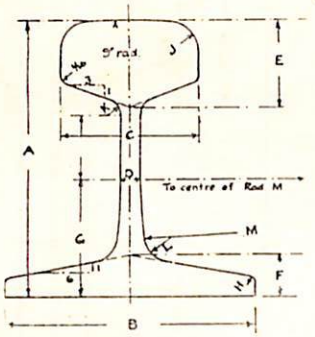
The sections marked * in the table were the standard until June 1922 when they were revised to the sections marked "R".

Abstracted by permission from British Standard Specification No. 9—1935, "British Standard Specification and Sections for Bull Head Railway Rails", official copies of which can be obtained from the British Standard Institution, 28, Victoria Street, London, S.W.1., price 5/4 post free.

TABLE No. 7.

BRITISH STANDARD FLAT BOTTOM RAILWAY RAILS.
DIMENSIONS OF SECTIONS.

B.S. No. and Nominal Weight	A	B	C	D	E	F	G	H	J	K	L	M
lb. per yard.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
25R	2 7/8	2 3/4	1 1/2	1/4	29/32	7/16	1 13/64		5/16	3/16		
30R	3 1/8	3	1 5/8	19/64	1	15/32	1 19/64		5/16	3/16	1/4	7 1/2
35R	3 3/8	3 1/4	1 3/4	21/64	1 3/32	1/2	1 25/64	1/16	5/16	3/16		
40R	3 5/8	3 1/2	1 7/8	23/64	1 9/64	17/32	1 33/64		3/8	7/32		
45R	3 7/8	3 3/4	1 31/32	3/8	1 7/32	9/16	1 39/64		3/8	7/32		
50R	4 1/8	3 15/16	2 1/16	25/64	1 19/64	19/32	1 23/32		3/8	7/32	11/32	9
55R	4 5/16	4 1/8	2 5/32	27/64	1 11/32	5/8	1 51/64		3/8	7/32		
60R	4 1/2	4 5/16	2 1/4	7/16	1 13/32	21/32	1 7/8	5/32	3/8	7/32		
65R	4 11/16	4 7/16	2 5/16	15/32	1 29/64	11/16	1 31/32		7/16	1/4		
70R	4 7/8	4 5/8	2 3/8	1/2	1 1/2	23/32	2 3/64		7/16	1/4		
75R	5 1/16	4 13/16	2 7/16	33/64	1 9/16	47/64	2 1/8		7/16	1/4		12
80R	5 1/4	5	2 1/2	17/32	1 39/64	49/64	2 13/64		7/16	5/16		
85R	5 7/16	5 5/16	2 9/16	35/64	1 43/64	25/32	2 9/32	3/16	7/16	5/16		
90R	5 5/8	5 3/8	2 5/8	35/64	1 23/32	13/16	2 23/64		1/2	3/8	3/8	
95R	5 13/16	5 9/16	2 11/16	9/16	1 25/32	53/64	2 7/16		1/2	3/8		
100R	6	5 3/4	2 3/4	9/16	1 27/32	27/32	2 1/2		1/2	3/8		
105	6 1/8	5 7/8	2 13/16	37/64	1 57/64	7/8	2 9/16		1/2	3/8		15
110	6 1/4	6	2 7/8	19/32	1 29/32	29/32	2 5/8	7/32	9/16	3/8		
115	6 3/8	6 1/8	2 15/16	39/64	1 15/16	15/16	2 11/16		9/16	3/8		
120	6 1/2	6 1/4	3	5/8	1 63/64	61/64	2 47/64		9/16	3/8		



KEY TO TABLE OF DIMENSIONS.

The dimensions figured on the key apply to all sections.

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TABLE No. 8.

INCHES CONVERTED TO DECIMALS OF A FOOT.

Inch	0″	1″	2″	3″	4″	5″	6″	7″	8″	9″	10″	11″
0	0	·0833	·1667	·2500	·3333	·4167	·5000	·5833	·6667	·7500	·8333	·9167
1/16	·0052	·0885	·1719	·2552	·3385	·4219	·5052	·5885	·6719	·7552	·8385	·9219
1/8	·0104	·0938	·1771	·2604	·3438	·4271	·5104	·5938	·6771	·7604	·8438	·9271
3/16	·0156	·0990	·1823	·2656	·3490	·4323	·5156	·5990	·6823	·7656	·8490	·9323
1/4	·0208	·1042	·1875	·2708	·3542	·4375	·5208	·6042	·6875	·7708	·8542	·9375
5/16	·0260	·1094	·1927	·2760	·3594	·4427	·5260	·6094	·6927	·7760	·8594	·9427
3/8	·0313	·1146	·1979	·2813	·3646	·4479	·5313	·6146	·6979	·7813	·8646	·9479
7/16	·0365	·1198	·2031	·2865	·3698	·4531	·5365	·6198	·7031	·7865	·8698	·9531
1/2	·0417	·1250	·2083	·2917	·3750	·4583	·5417	·6250	·7083	·7917	·8750	·9583
9/16	·0469	·1302	·2135	·2969	·3802	·4635	·5469	·6302	·7135	·7969	·8802	·9635
5/8	·0521	·1354	·2188	·3021	·3854	·4688	·5521	·6354	·7188	·8021	·8854	·9688
11/16	·0573	·1406	·2240	·3073	·3906	·4740	·5573	·6406	·7240	·8073	·8906	·9740
3/4	·0625	·1458	·2292	·3125	·3958	·4792	·5625	·6458	·7292	·8125	·8958	·9792
13/16	·0677	·1510	·2344	·3177	·4010	·4844	·5677	·6510	·7344	·8177	·9010	·9844
7/8	·0729	·1563	·2396	·3229	·4063	·4896	·5729	·6563	·7396	·8229	·9063	·9896
15/16	·0781	·1655	·2448	·3281	·4115	·4948	·5781	·6615	·7448	·8281	·9115	·9948

EXAMPLES :—$3\frac{13}{16}'' = \cdot3177' = \cdot318'$ to 3 places of Decimals.

$\cdot49' = 5\frac{7}{8}''$

TABLE No. 9.
LINEAR MEASURE.

	In.	Links	Ft.	Yds.	Poles	Chns.	Fur's	Cms.	Metres
1 Inch ..	—	—	—	—	—	—	—	2·54	
1 Link ..	7·92	—	—	—	—	—	—	20·12	
1 Foot ..	12	1·515	—	—	—	—	—	30·48	·3048
1 Yard ..	36	—	3	—	—	—	—	—	·9144
1 Pole ..	198	—	16½	5½	—	—	—	—	5·029
1 Chain ..	792	100	66	22	4	—	—	—	20·116
1 Furlong	—	—	660	220	40	10	—	—	201·16
1 Mile ..	—	—	5,280	1,760	320	80	8	—	1,609·31

TABLE No. 10.
AREAS OR SQUARE MEASURE.

	Sq. In.	Sq. Ft.	Sq. Yds.	Sq. Poles	Sq. Chns.	Roods	Acres	Sq. Cms.	Sq. Metres
1 Sq. Inch	—	—	—	—	—	—	—	6·451	—
1 Sq. Foot	144	—	—	—	—	—	—	—	·0929
1 Sq. Yard	1,296	9	—	—	—	—	—	—	·8361
1 Sq. Pole ..	—	272¼	30¼	—	—	—	—	—	25·29
1 Sq. Chain	—	—	484	16	—	—	—	—	—
1 Rood ..	—	—	1,210	40	2½	—	—	—	—
1 Acre ..	—	—	4,840	160	10	4	—	—	—
1 Sq. Mile ..	—	—	—	—	6,400	2,560	640	—	—

TABLE No. 11.
SECONDS PER QUARTER MILE EQUIVALENT TO MILES PER HOUR.

Seconds per ¼ mile	10	11	12	13	14	15	16	17	18	19	20	22
Miles per Hour ..	90	81¾	75	69¼	64¼	60	56¼	53	50	47½	45	41
Seconds per ¼ mile	24	26	28	30	32	36	40	45	50	60	75	90
Miles per Hour ..	37½	34¾	32¼	30	28	25	22½	20	18	15	12	10

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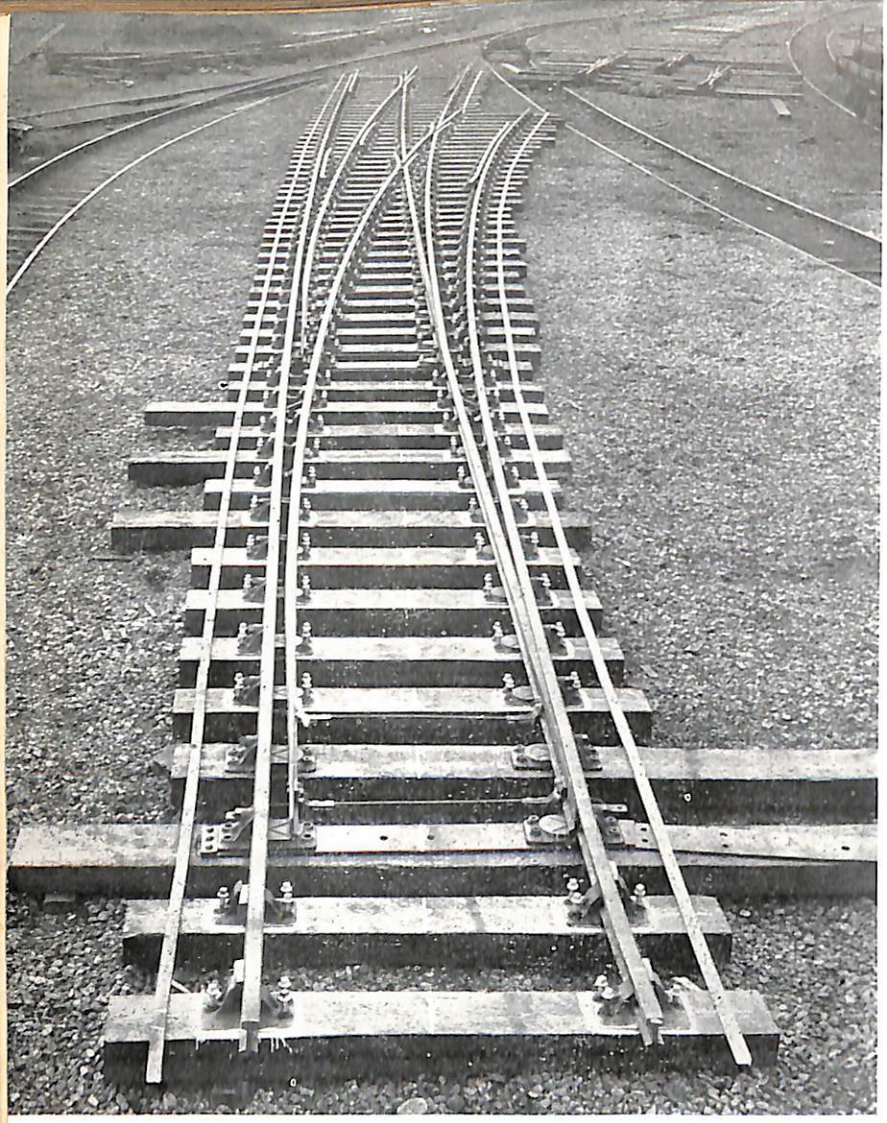

The above photograph shews a typical junction on curved track completely built up with timbers and two-level chairs as laid down in our yard for inspection for the L.M. & S. Railway.

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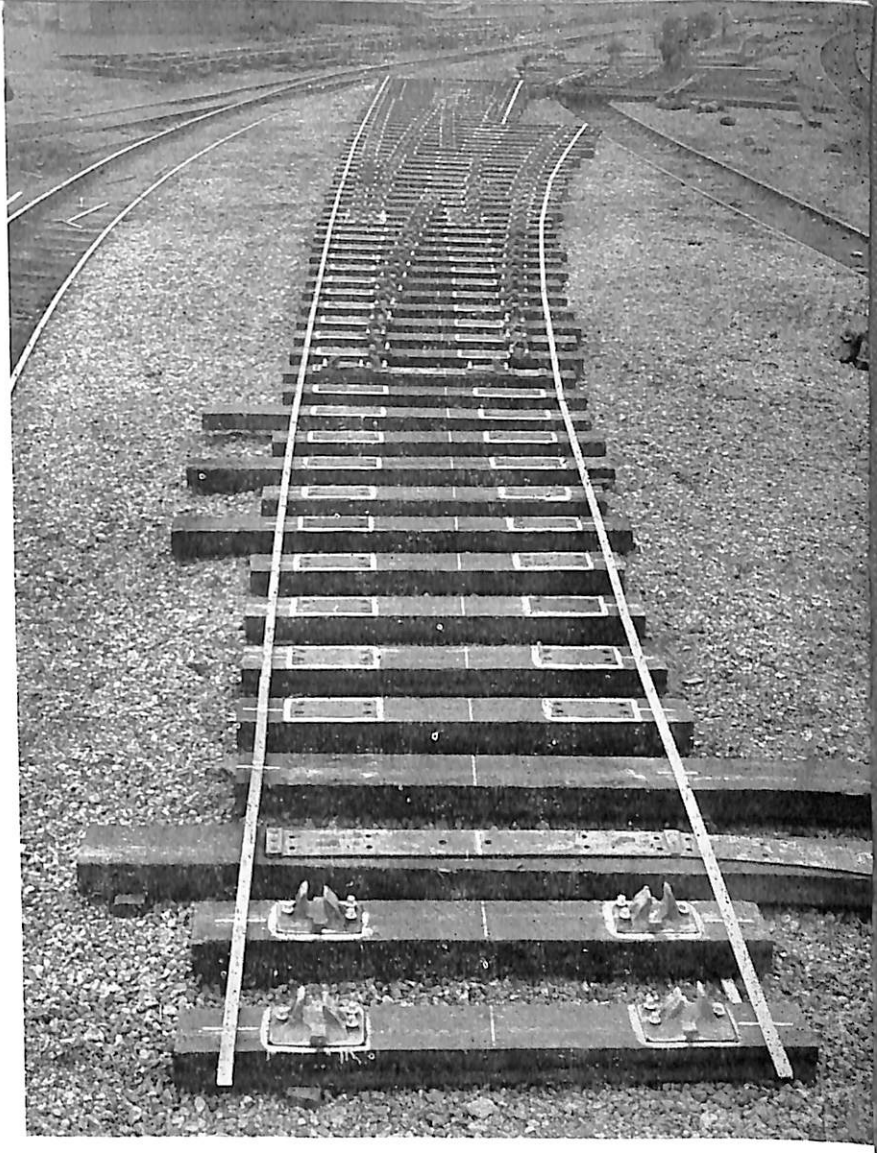

The above illustration shews the layout on the opposite page after the ironwork has been removed and as the timbering should be laid out on the renewal site preparatory to laying down the ironwork again.

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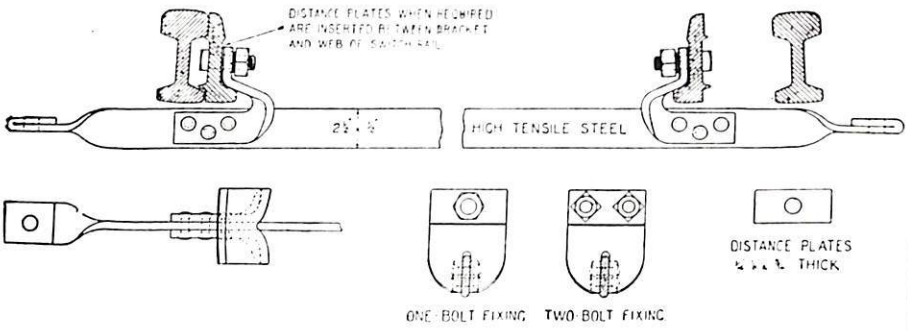
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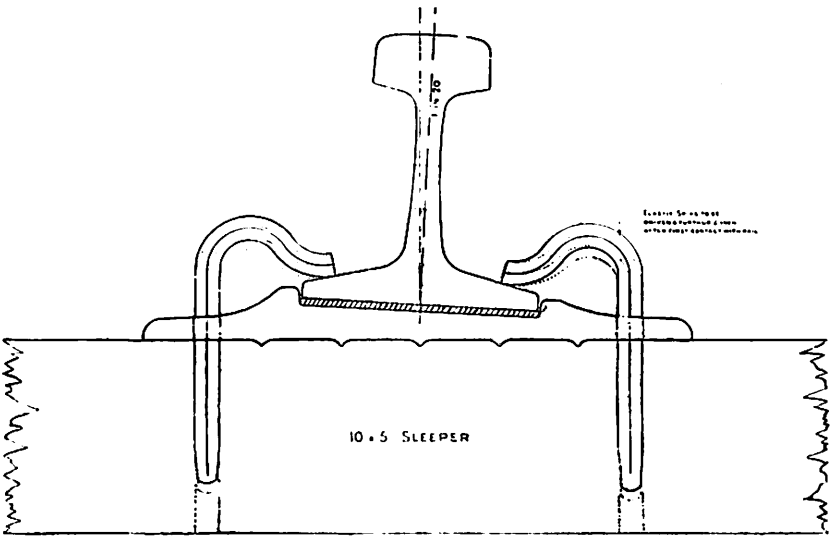

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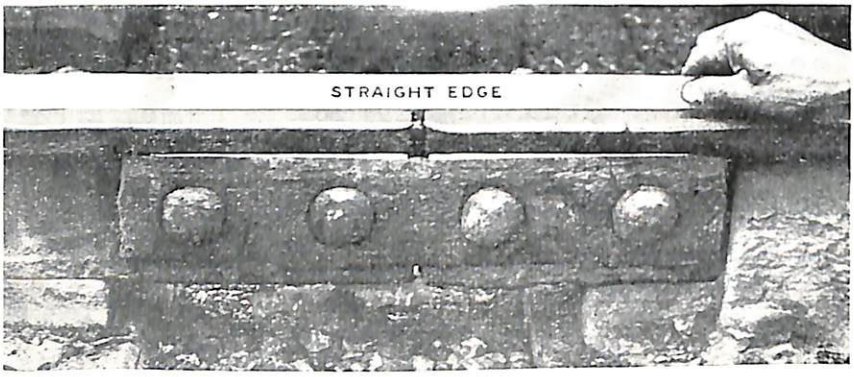

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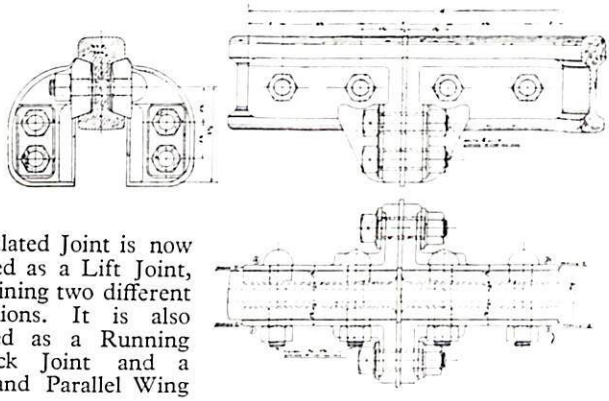

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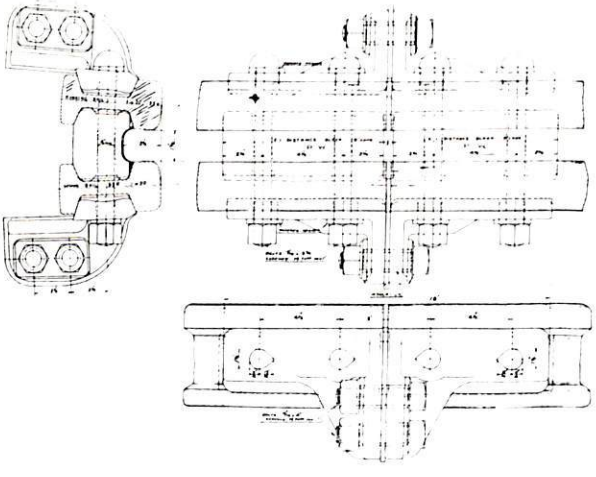

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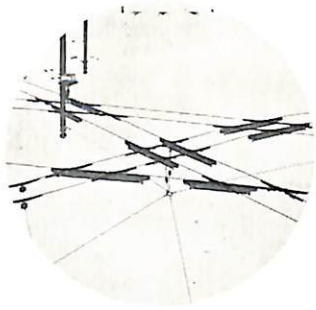

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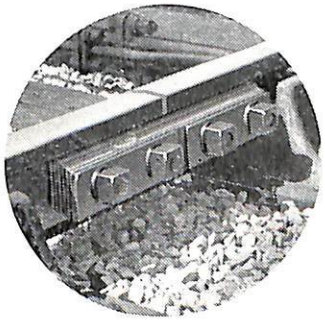

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No involuntary trip—the retaining pawl engaging the rack being spring-loaded.

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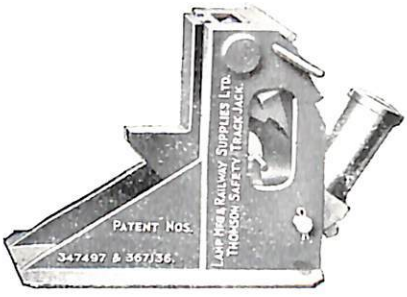

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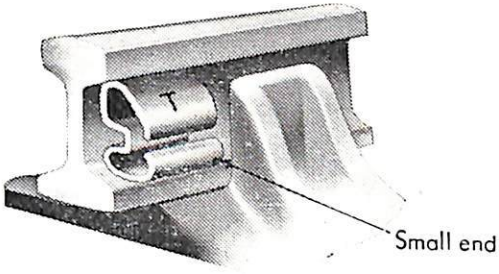

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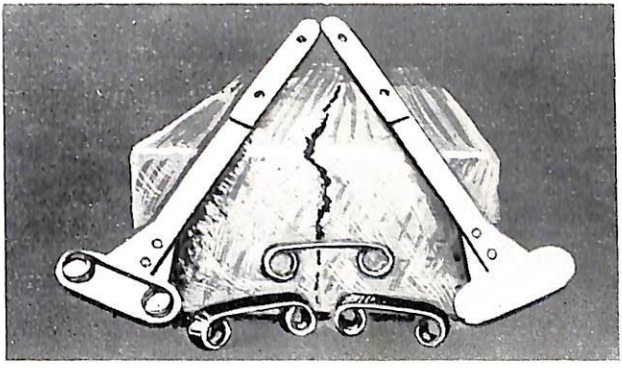

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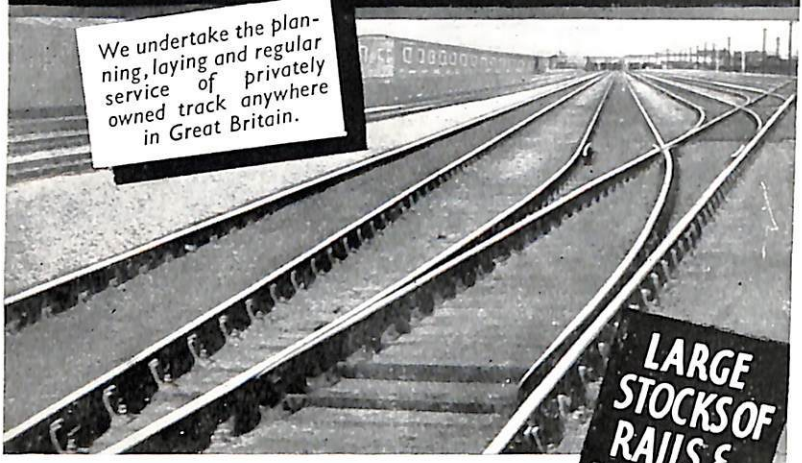
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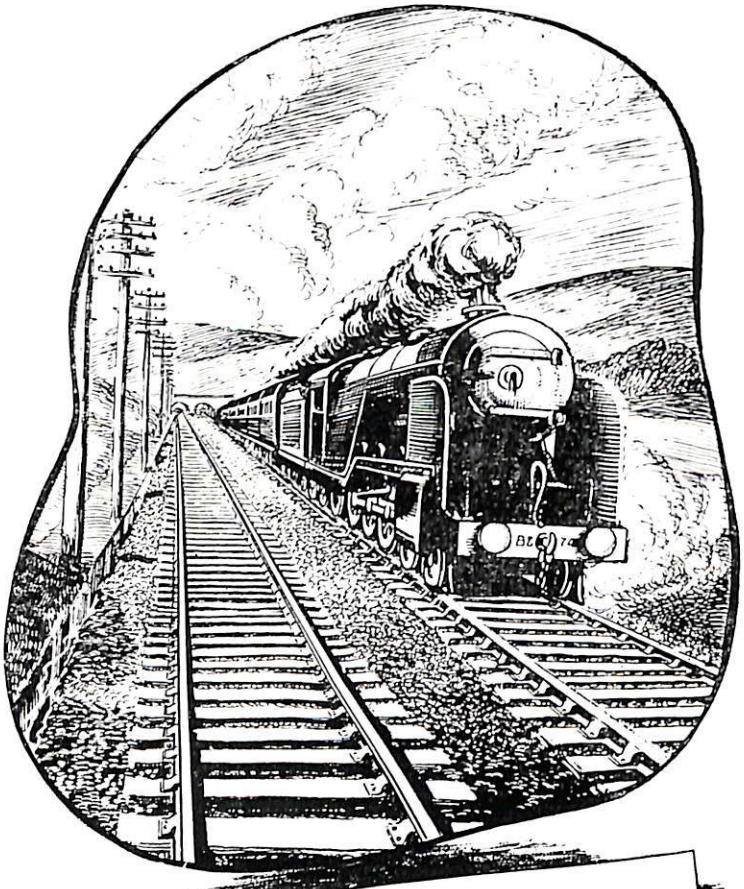

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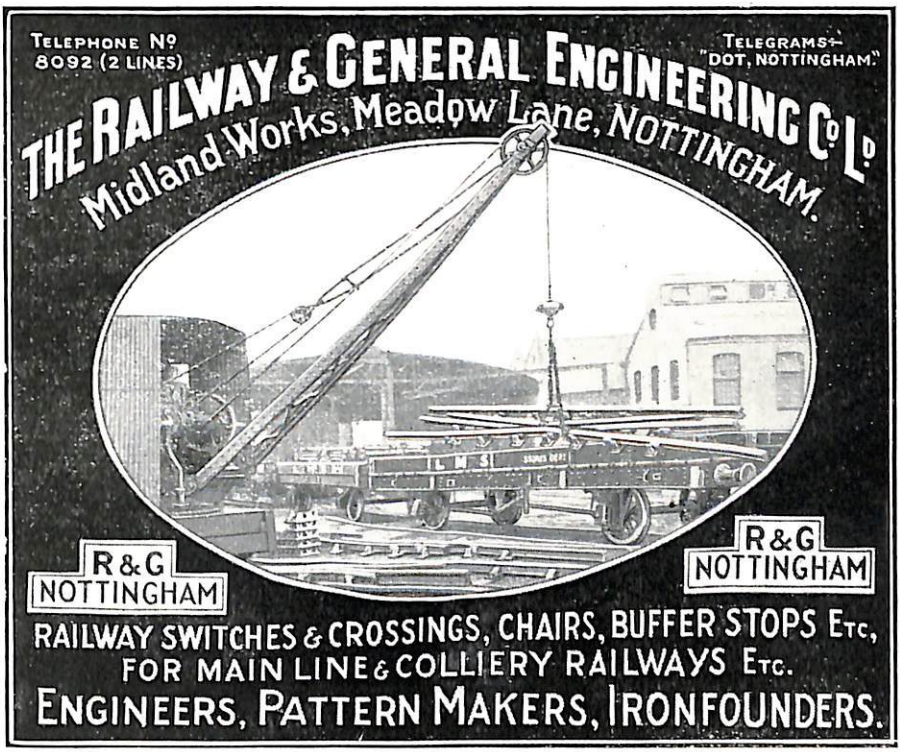
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